CHANGING GLOBAL CLIMATIC SCENARIO ON ENVIRONMENTAL PROCESSES ACROSS INDIA: ITS POSSIBLE CAUSES AND IMPACTS

By

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THESIS

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DECLARATION

I, hereby declare that this thesis entitled **"Changing global climatic scenario on environmental processes across India: its possible causes and impact"** is a bonafide record of research work done by me during the course of research and the thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or other similar title, of any other University or Society.

Place: **Lekshmi Mudra B**

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Dedicated to my beloved Grandfather and family

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ABBREVIATIONS

AMO	Atlantic Multi-decadal Oscillation
ANN	Annual
AO	Arctic Oscillation
AR 4	Assessment Report 4
AR 5	Assessment Report 5
AS	Arabian Sea
ASMWP	Arabian Sea Mini Warm Pool
CC	Cloud Cover
CPI	Central Peninsular India
EC (N)	East Coast (North)
EC (S)	East Coast (South)
ENSO	El-Nino Southern Oscillation
FAO	Food and Agricultural Organization
GDP	Gross Domestic Production
GIS	Geographical Information System
GMST	Global Mean Surface Temperature
GP	Ganga Plains
GPH	Geopotential Height
GrADS	Grid Analysis and Display System
HLUCs	Historical Land-Use Changes
IGC	Indira Gandhi Canal

IOD	Indian Ocean Dipole
IOWP	Indian Ocean Warm Pool
IPCC	Intergovernmental Panel on Climate Change
ISM	Indian Summer Monsoon
ISMR	Indian Summer Monsoon Rainfall
JF	January-February
JJAS	June-July-August-September
LLJ	Low Level Jet
LRS	Length of Rainy Season
LULC	Land Use and Land Cover
MAM	March-April-May
MEA	Millenium Ecosystem Assessment
MISO	Monsoon Intra-Seasonal Oscillations
MoEF	Ministry of Environment and Forest
MSLP	Mean Sea Level Pressure
NAM	Northern Hemisphere Annular Mode
NAO	North Atlantic Oscillation
NATCOM	National Communication
NATMO	National Atlas and Thematic Mapping Organization
NCAR	National Centre for Atmospheric Research
NCDC	National Climate Data Centre
NCEP	National Centers for Environmental Prediction
NCI	North Central India

NEI	North East India
NMI	North Mountainous India
NRC	National Research Council
NWI	North West India
NWIA	National Wetland Inventory and Assessment
OND	October-November-December
PW	Precipitable Water
RMSE	Root Mean Square Error
RSDI	Rainfall Spatial Distribution Index
SAC	Space Application Centre
SAT	Surface Air Temperature
SD	Standard Deviation
SO	Southern Oscillation
SOI	Southern Oscillation Index
SPI	South Peninsular India
SST	Sea Surface Temperature
TA	Tibetan Anticyclone
TBO	Tropospheric Biennial Oscillation
TEJ	Tropical Easterly Jet
TT	Tropospheric Temperature
UNESCO	United Nations Educational, Scientific and Cultural Organization
UNFCCC	United Nations Framework Convention on Climate Change
WC	West Coast

WC (S)	West Coast (South)
WG 1	Working Group 1
WG 2	Working Group 2
WGMS	World Glacier Monitoring Service
WHO	World Health Organization

INTRODUCTION

CHAPTER 1

INTRODUCTION

The United Nations Framework Convention on Climate Change (UNFCCC) defined the climate change as "a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods'' in contrary to the definition given by the Intergovernmental Panel on Climate Change (IPCC) as "any change in climate over time whether due to natural variability or as a result of human activity". In short, Earth's climate has always been changing from time to time. Throughout its long history, climate change over the past several hundred years suggest ~30 year cycles of global warming and cooling, on a general rising trend from the Little Ice Age. However, records of past climate change suggests an altogether different scenario for the 21st century (Easterbrook, 2011). Climate has changed when the planet received more or less sunlight due to subtle shifts in its orbit, as the atmosphere or surface changed, or when the sun's energy varied (Foucal *et al*., 2006). Before humans, the changes in climate had entirely resulted from various natural phenomena. The changes in the climate prior to the industrial revolution during 1700's can be explained by natural causes. Recent climate changes, however, cannot be explained by natural causes alone. Research indicates that natural causes are very unlikely to explain most observed warming, especially warming since the mid-20th century. Rather, human activities can very likely explain most of this warming (NRC, 2010). The changes in land use and land cover have changed earth's reflectivity. Processes such as deforestation, reforestation, desertification, and urbanization often contribute to changes in climate in the places they occur. These effects may be significant regionally, but are smaller when averaged over the entire globe.

Global warming and climate change are terms for the observed century-scale rise in the average temperature of the earth's climate system and its related effects. It is also used to describe a gradual increase in the average temperature of the earth's atmosphere and its oceans, a change that is believed to be permanently changing the earth's climate. The scientific consensus on climate change related to global warming is that the average temperature of the earth has risen between 0.4 and 0.8 °C over the past 100 years. The global average surface temperature rose 0.6 to 0.9 ^{o}C (1.1 to 1.6 °F) between 1906 and 2005, and the *rate* of temperature increase has nearly doubled in the last 50 years. Anticipated effects include warming global temperature, rising sea levels, changing precipitation pattern, and expansion of deserts in the subtropics. Warming is expected to be the greatest in Arctic region with the continuing retreat of glaciers, permafrost and sea ice. Other likely changes include more frequent extreme weather events including heat waves, droughts, heavy rainfall and species extinction due to shifting temperature and rainfall regimes. Effects significant to humans include the threat to food and nutritional security and the abandonment of populated areas due to flooding (Battisti and Naylor, 2009) and droughts. Increased anthropogenic activities such as industrialization, urbanization, deforestation, agriculture, change in land use and land cover patterns lead to emission of the greenhouse gases due to which rate of global warming is faster, resulting to climate change. The adverse impacts of climate change on the society linked sectors are significant with extreme weather conditions, changing rainfall patterns, droughts, groundwater crisis, glacier melts and the sea level rise posing challenges to food and nutritional security, energy security, water security and public health. In 2003, for example, extreme heat waves caused more than 20,000 deaths in Europe and more than 1,500 deaths in India. Scientists have linked the deadly heat waves to climate change and warn of more to come (Majumder, 2015).

The climate variation has tremendous socio-economic impact in the tropical regions, especially the impact of monsoon over India and neighbouring countries in South Asia. The extreme events, such as the extreme rainfall events and storm surges related to cyclonic activities had devastating consequences on the population and economy of the region. The consecutive flash floods over three major metro cities in the same year viz. Mumbai in July 2005, Chennai in October 2005 and again in December 2005 and Bangalore in October 2005 caused heavy damages in economy and loss of life. The Ladakh floods occurred on 6th August 2010 across a large part of Ladakh, a region of the northernmost Indian state of Jammu and Kashmir. Damages occurred in 71 towns and villages including the main town in the area, Leh. At least 255 people were reported to have died, after a cloudburst and heavy overnight rains triggered flash floods, mudslides, and debris flows. In June 2013, a multi-day cloudburst centered on the North Indian state of Uttarakhand caused devastating floods and landslides becoming the country's worst natural disaster since the 2004 tsunami. In 2014, the state of Andhra Pradesh (Visakhapatnam) was devastated due to Hud-Hud cyclone along the coast in October 2014. The Jammu and Kashmir and adjoining areas received heavy rainfall from 2nd September 2014 onwards, during last stage of monsoon in India. In May 2015, India was stuck by severe heat waves, and caused the deaths of more than 2500 as of June 3, 2015. Therefore, the global warming and climate change is a threat in the form the weather extremes and its frequency are likely to increase in the ensuing decades as per the latest IPCC report (AR5, 2013).

Keeping in view of changing global climatic scenario that largely modulates the environmental processes regionally and locally as well as the limited practical value of the large-scale rainfall studies, the study aims

1. To examine the rainfall variability across the country and its possible causes.
2. To access the land use and land cover change of different parts of the country.
3. To address the impacts of changing climatic scenario to the environmental processes.

REVIEW OF LITERATURE

CHAPTER 2
REVIEW OF LITERATURE

Extensive survey on various published national and international research papers as well as books has been conducted to review literature in all aspects related to the objectives of the study undertaken. It makes better understanding of the subject.

Climate change is real. Several studies were done to find out the ill effects of climate change on various sectors like agriculture, socio-economy, health etc. Frequency of extreme events like flood, drought, heat waves, cyclones, storm surges, etc. is increasing. The globally averaged combined land and ocean temperature data as calculated by a linear trend show a warming of 0.85^{o}C over the period 1880-2012 (IPCC, AR5). In the wake of warming scenario, it is expected to get good rainfall, but it is not happening. Due to increasing global warming and associated climate change, Indian monsoon is showing vagaries. All India summer monsoon rainfall is decreased by 4.51 per cent since 1964-65 (Singh, 2013). Hence it is very essential to understand more about processes driving the monsoon, its seasonal cycle and modes of variability.

Singh *et al*. (2005) studied spatial variation of the seasonal and monthly rainfall by examining interannual variation of an optimum number of four rainfall zones under different rainfall conditions viz., very dry (VD), dry (D), wet (W) and very wet (VW), identified on the mean rainfall chart of the particular period (season/month) of equal size (25%) area of the country. The area of the country under different rainfall conditions was obtained from this study. Based on this, a Rainfall Spatial Distribution Index (RSDI) defined by lumping VD, D, W and VW areas in order to assess the rainfall situation (both in terms of amount and areal distribution) for the country as a whole.

2.1 Factors influencing Indian summer monsoon

Numerous studies (Ramage, 1971; Wang and Lin, 2002; Yang *et al.*, 2004; Ding and Johnny, 2005) revealed and well documented about the problems of the Asian Summer monsoon of being its huge spatial coverage and also the demarcation of this system into two sub-systems viz, the Indian summer monsoon, and the East Asian summer monsoon. The millennial-scale climate change and their fluctuations are pronounced in the records of the East Asian summer monsoon system (Thompson *et al*., 1997; Wang *et al*., 2001; Nagashima *et al.*, 2011; Arzel and England, 2012).

2.1.1 El-Nino and ENSO

Important features of Indian summer monsoon rainfall (ISMR) variability and its associated linkage with El-Nino have been studied (Pant and Parthasarathy, 1981). Several other studies on the impact of El-Nino on Indian summer monsoon rainfall are reported (Angell, 1981; Rasmusson and Carpenter 1983; Ropelewski and Halpert 1987; and Shukla, 1987).

Shukla and Paolino (1983) found that the tendency of Darwin pressure anomaly before the monsoon season is a good indicator of monsoon anomaly. If the Darwin pressure anomaly during pre-monsoon season is below normal, and if the Darwin seasonal pressure anomaly has falling, a non occurrence of drought over India can be predicted with a very high degree of confidence. Similarly, above normal pressure and rising seasonal pressure anomaly over Darwin is a very good indicator of non occurrence of very high rainfall over India. During recent decades, many atmospheric researchers (Krishnakumar *et al*., 1999; Kripalani and Kulkarni, 2001; Chang *et al*., 2001) tried to understand the possible causes of the weakening of the impact of El-Nino Southern Oscillation (ENSO) on the Indian summer monsoon rainfall.

Several studies demonstrated that the evolution of ENSO is different before and after the 1976–77 regime shifts (Wang, 1995; An and Wang, 2000; Wang and An, 2001). The studies of Meehl (1997) reveal that on inter-annual timescales, a large component of the Asian summer monsoon variability consists of its biennial character, with a relatively strong event that tends to be followed by a relatively weaker in the next year. This biennial variability has been mentioned as the tropospheric biennial oscillation (TBO) (Meehl, 1994; Meehl, 1997). Krishnakumar *et al.* (1999) postulated of having two possible reasons for the breaking of inverse relationship between ENSO and ISM (Indian Summer Monsoon) in recent decades. A southeastward shift in the Walker circulation anomalies associated with ENSO events may lead to a reduced subsidence over the Indian region, thus favouring normal monsoon conditions. Additionally, increased surface temperatures over Eurasia during winter and spring, which are a part of the mid latitude continental warming trend, may favour the enhanced land-ocean thermal gradient which is in turn conducive to a strong monsoon circulation.

In the last two decades, the Indian Ocean Dipole (IOD, Saji *et al*., 1999; Webster *et al*., 1999) has been identified as potential trigger of the ENSO-monsoon connection (Ashok *et al*., 2001; Li *et al*., 2003), but its intensity as well as the factors responsible for direct or indirect impact on the relationship has not been clearly identified yet (Meehl *et al*., 2003; Wu and Kirtman, 2004; Cherchi *et al*., 2007). According to the studies of Cherchi and Navarra (2013), El-Nino and positive IOD events tend to co-occur with larger anomalies either in the Indo-Pacific ocean sector or over India, while La Niña and negative IOD behaves random in nature. From the observed record, it is also found that the ENSO-IOD correlation is strong, positive and significant since mid-60s.

2.1.2 Other teleconnections

According to Buermann *et al*. (2005), there was a significant positive correlation between Arctic Oscillation and rainfall during the month of June. The Atlantic Multi-decadal Oscillation (AMO) produces persistent weakening or strengthening of the meridional gradient of tropospheric temperature (TT) by setting up negative (positive) TT anomaly over Eurasia during northern late summer or autumn resulting in early (late) withdrawal of the south west monsoon and persistent decrease (increase) of seasonal monsoon rainfall (Goswami *et al*., 2006). The study also revealed that on inter–annual time scales, strong North Atlantic Oscillation (NAO) or Northern Hemisphere Annular mode (NAM) influences the monsoon by producing similar TT anomaly over Eurasia. Both the North Atlantic Oscillation (NAO) and Southern Oscillation (SO) had the joint effect on the Indian Summer Monsoon Rainfall rather than their individual effect (Kakade and Dugam, 2006).

2.1.3 Jet streams and circulation patterns

The active-break cycles of rainfall is closely associated with the monsoon intra-seasonal oscillations (MISO) with horizontal scale much larger than the Indian continent and its northward propagation of convection and precipitation from equatorial Indian Ocean to Indian subcontinent with timescales of 30-60 days (Sikka and Gadgil, 1980; Goswami, 2011).

Terray and Dominiak (2005) postulated the triggering process of coupled air–sea processes in the tropical eastern Indian Ocean during the following seasons due to the climate shift during 1978-79. The southern Indian Ocean SST (Sea Surface Temperature) anomalies produced by Mascarene high pulses during boreal winter could be one of the reasons of this process. This air-sea interaction produces a persistent remote forcing on the Pacific climate system and further promoting wind anomalies over the western equatorial Pacific and modulating the regional Hadley cell in the southwest Pacific. Bansod *et al.* (2012) studied about the recent changes in four selected regional circulation parameters viz., zonal wind at 200 hPa level over Tibetan Anticyclone region (TA_{U200}), zonal wind at 100 hPa over peninsular India i.e. Tropical Easterly Jet (TEJ_{U100}), meridional wind (Somali Jet) at 850hPa over Somali Coast (SJ_{V850}) and meridional wind at 850hPa over Arabian Sea (AS_{V850}). These parameters are subjected to study their influence on ISMR. The results show that AS_{V850} and TEJ_{U100} show decreasing tendency which in turn leads to the weakening of the moisture transport mechanism over the Indian sub-continent during the monsoon season whereas the other parameters TA_{U200} and SJ_{V850} show increasing tendency.

The differential heating in the upper troposphere, with associated increase (decrease) in atmospheric stability (Meridional gradient temperature), weakens the Asian summer monsoon circulation, promote a northward shift of the monsoon circulation and a widening of the local Hadley cell in the eastern Indian sector (Sooraj *et al*., 2014). The low level jet stream (LLJ) brings moisture to the Indian landmass from surrounding oceans during summer monsoon. It is observed that widening of tropical belt and poleward shift of mid-latitude jet streams occur due to global warming. According to the studies of Sandeep and Ajayamohan (2015), a poleward shift in LLJ has been observed in both observations and coupled model simulations. This results in the drying (wet) trend in the southern (northern) part of the west coast of India for last three decades.

2.1.4 Snow cover over Eurasia

Harzallah and Sadourny (1997) found out that strong monsoons are preceded by weak snow cover extent over Eurasia in winter, by warm sea surface temperatures over Nino 3 region (eastern equatorial Pacific between 5N-5S, 150W-90W) and an important precursor is a negative centre of geopotential height over Siberia appearing as early as late summer. It is observed that 57 per cent of heavy snow events and 24 per cent of light snow events over west Eurasia are followed by deficient and excess ISMR respectively (Dash *et al*., 2004). The study of Dash *et al.* also revealed that because of the west Eurasian snow anomalies, the midlatitude circulations in winter through spring showed significant changes in the upper and lower level wind, geopotential height, velocity potential and stream function fields. Such changes in the large-scale circulation pattern may be interpreted as precursors to weak or strong monsoon circulation that would modulate the deficient or excess ISMR.

2.1.5 Sea surface temperature

A clear shift in the withdrawal date of ISMR is observed from the long time series of rainfall data (Sabeerali *et al*., 2012). Before (after) the climate shift most of the withdrawal dates fall under late (early) and resulted longer (shorter) length of rainy season (LRS). One of the possible reasons prior to climate shift is considered to be the sea surface temperature (SST) anomalies in the eastern equatorial Pacific Ocean and the Arabian Sea that exert a strong influence on both the withdrawal and the LRS. After the climate shift, the influence of the eastern equatorial Pacific Ocean SST has decreased and the influence of the Arabian Sea SST are almost non-existent (Sabeerali *et al*., 2012).

Arabian Sea Mini Warm Pool (ASMWP) is a part of the Indian Ocean Warm Pool (IOWP) and formed in the eastern Arabian Sea prior to the onset of the summer monsoon season. The study also revealed that warm pool should attain its maximum areal extent and intensity 2 weeks prior to the onset of monsoon over Kerala and get dissipated with the commencement of monsoon. It was also found out that maximum core temperature and wide coverage of the warm pool was observed during the excess monsoon years compared to normal and deficient monsoon years (Neema *et al*., 2012).

2.1.6 Cloud cover

Cloud feedback is the coupling between cloudiness and surface air temperature in which a change in surface air temperature could lead to a change in volume of clouds, which could then amplify or diminish the initial temperature perturbation. An increase in surface air temperature could increase evaporation and hence the precipitable water in the atmosphere; this in turn might increase the extent of cloud cover. According to Willium and Houze (1987) the large cloud clusters exhibit meso-scale organization that leads to most of the vertical transport of the energy from the planetary boundary layer to the upper troposphere as well as, in turn, the rainfall. The studies like role of cloud properties in relation with summer monsoon were conducted (Kiran *et al*., 2009). The study showed statistically significant variations of cloud properties over Central and North East India.

2.1.7 Surface temperature

With the global climate model projections of probable increase of global mean temperature between 1.4 and 5.8° C by 2100 (IPCC, 2007), it is expected to have severe impacts on the global hydrological system, eco-systems, sea level, crop production and related produces. The IPCC report (2007) stresses the risks of global warming with its predicted rise in global temperatures between 0.3 and 4.8° C and a rise of up to 82 cm in sea levels by the late 21st century due to melting of ice and expansion of water.

2.1.7.1 Surface temperature trends in India

Pant and Hingane (1988) reported decreasing trend in mean annual surface air temperature for 1901-1982 over the northwest Indian region consisting of meteorological sub-divisions of Punjab, Haryana, West Rajasthan, East Rajasthan and West Madhya Pradesh. Regarding temperature trends over India, the mean maximum temperature series showed a falling trend at some stations; it showed a falling trend at some stations. The mean minimum temperature showed an increasing as well as decreasing trend. At most of the stations in the south, central, and western parts of India, a rising trend was reported. Some stations located in the north and northeastern India showed a declining trend in annual mean temperature (Jain and Kumar, 2012). Similar kind of studies regarding trend analysis of temperature over India were reported (Rao, *et al*., 2005; Paul *et al*., 2014). According to Paul et al., a significant increase in July Temperature over arid zones of the country is observed since 1972.

2. 2 Land use and land cover impacts

The primary source of our natural resources which is also known as the earth resources is being largely affected by the changing global climatic scenario. Both the renewable and non-renewable resources are of a tremendous value to human culture and living beings (Dasman, 1959; Schumancher, 1973) in the form of air, heat, natural vegetation, soil, wild animals, metals, fossil fuels etc. The natural resources are not resources as they are inert unless they are used by human beings. Resources have functional relationship between man's abilities to exploit substances and natural environment or natural ecosystem. They are, however, naturally occurring substances that are considered valuable in their relatively unmodified natural form. A natural resource's value rests in the amount of the material available and the demand for it. The latter is determined by its usefulness to production.

Changing global climate largely modulates all those processes and cycles that occur naturally in the environment without any intervention which is known as the environmental processes. It also plays a crucial role in changing the environment of wetland by causing changes in the environment of habitats of living things and the numbers of individuals or species, and the studies for influence of climate change on wetland are underway to assess them. Mortsch (1998) and Erwin (2009) had made an analysis on the influence of climate change on the ecology of wetland and hydrological characteristics. The high spatial resolution satellite observations also showed a considerable decrease of the desert and semi-arid regions, especially over the western part of Rajasthan and a concurrent significant increase in crop areas. This was considered as a consequence of the Indira Gandhi Canal irrigation bringing water over the arid western Rajasthan, thus leading to increase of the vegetation areas (Kharol *et al*. 2013).

The changes in land use and land cover had changed earth's reflectivity. Processes such as deforestation, reforestation, desertification, and urbanization often contributed to changes in climate in the places they occur. These effects may be significant regionally, but are smaller when averaged over the entire globe. Land has been considered to have no intrinsic value but reserved a bigger place to serve human needs (Mazurski, 1991). The land use and land cover analysis for the whole country is consistent with decreasing tendency in the arid area of the country as reported by Singh *et al.* (1992), and shrinking tendency in deserts of the whole India were based on land use and land cover (LULC) data of the period 1880–1980. Earlier it was suggested that the Indian desert was spreading (Winstanley, 1973). Land used for arable cultivation over the whole country has been increased in particular during 1880–1980.

Kharol *et al*. (2013) had attributed recent land use or land cover changes (an increase in crop-land and vegetated areas of ~57 per cent in the eastern Rajasthan and ~68 per cent in the western Rajasthan) in the Rajasthan state due to the Indira Gandhi Canal (IGC). Yamashima *et al.* (2014) investigated the impact of historical land-use changes (HLUCs) from 1700 to 1850 on the onset of the Indian summer monsoon, focusing on the onsets of broad-scale ISM circulation and the local rainy season and their relationships by conducting three equilibrium experiments under 1700, 1850, and 1992 conditions. The results showed that HLUC decreased rainfall amounts by more than 2 mm per day during the onset phase and delayed the onset date of the local rainy season by approximately four pentads over the Indian subcontinent with large spatio-temporal variability.

According to Tian *et al*. (2014) the major LULC changes include the loss of forests, expansion of cropland, and urbanization during 1900–2013. However, deforestation decreased after the 1980s due to formulation of government policies to protect forests. Cropland expansion rate was greater primarily due to expansion of irrigation facilities, farm mechanization, electrification, and use of high yielding crop varieties that resulted from Government policies of achieving self-sufficiency in food production. Our results have shown that urbanization which was negligible during earlier period became one of the most important land conversions in the recent decades due to population and economic growth in India.

The forest cover of the country has been declining since last several years. The consequences of the changes in land cover are the changes in surface albedo, ground wetness, surface roughness etc. The influence of deforestation is modelled by the changes in the surface parameters such as land cover (Gupta, 2005). The model is integrated for five years with forest cover replaced by grassland in three different classes, viz. 100 per cent, 50 per cent, 25 per cent. The model simulations (for JJA period), for 100 per cent deforestation, are showing that there will be change in spatial distribution of rain rate in India i.e. over northern part of India, rain rate is expected to decrease up to 2mm/day whereas over Southern part of India, including Arabian Sea and Bay of Bengal, the rain rate will increase up to 5mm/day. In Africa and north-east India, where deforestation was done, rain rate will decrease up to 4mm/day. These changes in rain rate are due to changes in global circulation, caused due to large scale deforestation.

Global climate change is expected to become an important driver for delineation and change in wetland ecosystem (MEA, 2005 and UNESCO, 2007). These findings are important for Indian subcontinent where the mean atmospheric temperature and frequency of occurrence of intense rainfall events had increased, while the number of rainy days and total annual amount of precipitation had decreased due to rise in the concentration of greenhouse gases such as CO_2, CH_4 and N_2O in the atmosphere (Bates *et al*., 2008, Bassi *et al*., 2014).

According to Erwin (2009), climate change will affect the hydrology of individual water-based ecosystems with changes in precipitation and temperature regimes. The dependence of agriculture, drinking water, and energy production on the Indian summer monsoon rainfall makes it the lifeline for most of the population. Rainfall variability has also large impact on land formation, biodiversity, desertification, food security etc. This will affect the livelihoods of many people, who directly or indirectly depend on those natural resources and thus calls for better understanding and management practices for environmental process. The paradoxical situation of the Asian summer monsoon is the weakening performance of summer monsoon rainfall though the surface air temperature of the northern hemisphere is rising. Though major parts of the country are experiencing decreasing trend, northwest India is experiencing positive trend (Singh, 2013). However, due to enormous spatial variation in rainfall amount and heterogeneous characteristics of point-rainfall temporal fluctuation, the representation of the areally averaged rainfall series of the country is limited (Singh *et al*., 2009; Singh, 2013). Understanding the science of climate change and impact of rising trend in global tropospheric temperature on environment, hydrometeorological services and society are important problems of contemporary research because of its strong influence on the socio-economy (Singh, 2013).

2.3 Impact of climate change on environment

Singh and Kumar (1997) found that snowmelt and glacier melt increases linearly with temperature rise. He also found that snowmelt runoff, glacier melt runoff, and total stream flow over central Himalayas increased 4-18 per cent, 33-38 per cent, and 6-12 per cent respectively in +2 ^{o}C scenario. Kang *et al*., (2010) reported that increasing permafrost temperatures and permafrost degradation have occurred in the Tibetan Plateau. The studies of Nie *et al.* (2014) found out that the glacial lakes in the Central Himalaya showed an expansion in area and increase in number from 1990 through 2010. The Tibetan plateau glaciers and lakes changed significantly under global warming; glaciers retreated and shrunk while lake area expanded and water level rose (Zhiguo, 2014). The World Glacier Monitoring Service (WGMC) at the University of Zurich has compiled worldwide data on glacier changes for more than 120 years and published a new a comprehensive analysis of global glacier changes. In this study, observations of the first decade of the 21st century (2001-2010) were compared to all available earlier data from in-situ, air-borne, and satellite-borne observations as well as to reconstructions from pictorial and written sources (Zemp *et al.*, 2015). The study revealed the melting of glaciers at rates never seen before in recorded history with the first decade (2001-2010) of the current century seeing thrice the rates over last century. The observed glaciers currently had been loose between 0.5 m to 1.5 m of its ice thickness every year; this is two to three times more than the corresponding average of the 20th century (Zemp *et al.*, 2015).

The impacts of climate change for India are large with extreme weather conditions, changing rainfall patterns, droughts, groundwater crisis, glacier melts, sea level rise posing challenges to agriculture and food security, energy security, water security and public health. Droughts and floods lead to large-scale migration in search of alternative livelihoods, loss of human life due to stress, suicide, starvation or unhygienic conditions, and increased social conflict. Due to its profound impact on economy and society, the prediction of monsoon rainfall and the occurrence of drought are vital for the nation. Sea levels rise because warmer water occupies more space than colder water, a process known as thermal expansion. Faster rate of melting glaciers compound the problem by leaving more fresh water into the oceans. Rising seas threaten to inundate low-lying areas and islands, threaten dense coastal populations, erode shorelines, damage property and destroy ecosystems such as mangroves and wetlands that protect coasts against storms. Warming is expected to be greatest in Arctic region with the continuing retreat of glaciers, permafrost and sea ice. Other likely changes include more frequent extreme weather events including heat waves, droughts, heavy rainfall; and species extinctions due to shifting temperature regimes. Effects significant to humans include the threat to food security from decreasing crop yields and the abandonment of populated areas due to flooding (Battisti and Naylor, 2009). Sea level rise associated with climate change could displace tens of millions of people in low lying areas, especially in developing countries. Inhabitants of some small island countries that rest barely above the existing sea level are already abandoning their islands, some of the world's first climate change refugees (NATCOM, 2004).

Climate change may increase the spread of infectious diseases, mainly because warmer temperatures allow disease-carrying insects, animals and microbes to survive in areas where they were once not survived by cold weather. Diseases and pests that were once limited to the tropics such as mosquitoes that carry malaria may find hospitable conditions in new areas that were once too cold to support them. The World Health Organization (WHO) estimates that climate change may have caused more than 150,000 deaths in the year 2000 alone, with an increase in deaths likely in the future (WHO, 2004). Worldwide, approximately 100 million people live within three feet of sea level (Akpeninor, 2013). Climate change brings health risks to the World's most vulnerable human populations. In 2003, for example, extreme heat waves caused more than 20,000 deaths in Europe and more than 1,500 deaths in India. Scientists have linked the deadly heat waves to climate change and warn of more to come (Majumder, 2015).

Climate change in India may pose additional stresses on ecological and socioeconomic systems that are already facing tremendous pressures from rapid urbanization, industrialization and economic development. The warming may be more pronounced in northern parts of India and extremes in minimum and maximum temperatures are expected to increase under changing climate. Gross per capita water availability will decline from 1820 m^3/yr in 2001 to as low as 1140 m^3/yr in 2050 (Gupta and Deshpande, 2004). Corals in Indian Ocean will be exposed to summer temperatures that will exceed the thermal thresholds observed over the last 20 years. Presently the districts of Jagatsinghpur and Kendrapara in Odisha; Nellore and Nagapattinam in Tamilnadu; and Junagadh and Porbandar districts in Gujarat are most vulnerable to impacts of increased frequency and intensity of cyclones (NATCOM, 2004). The past observations on the mean sea level along the Indian coast show a long term (100 year) rising trend of about 1.0mm/year, while, the recent data shows a rising trend of 2.5mm/year in sea level along Indian coast (Mitra, 2013). One meter rise in sea level is projected to displace approximately 7.1 million people in India with a loss of about 5764 Sq. km of land area (NATCOM, 2004).

Small and marginal farmers practicing agriculture on rain-fed farms will bear the brunt of climate change. Rice and wheat are the staple food of millions of people (FAO, 2012). The cultivation of rice began in China around 2500 BC and it spread out to India and Sri Lanka until it was introduced in Greece, Europe, North Africa, Brazil, and in Southeast Asia. The cultivation of wheat began during Neolithic period probably as early as 4000 BC to 5000 BC. Despite the declining rice production rate experienced in 2009, India made a huge progress over the last four decades, and it had been the primary contributor to the

33 per cent GDP of the country (FAO, 2012). Hence, about 2/3rd of employment in the country came from the agriculture sector. One of the reasons why food prices were increasing all across the world was the shortfall in agricultural output. According the Food and Agricultural Organization (FAO) of the United Nations, 80 per cent of world rice and wheat production came from ten countries out of which the major contribution came from China and India. Aggarwal *et al*. (2007) had shown that in northern India rice yield during last three decades showed a declining trend and this was possibly related to increasing temperatures. Similar trends had also been noticed recently in Philippines (Peng *et al.*, 2004). IPCC (2007b) had projected that crop productivity is likely to increase slightly in temperate regions for local mean temperature increases of up to 1-3 ^{o}C depending on the crop. This may decrease with further increase in temperature in some regions. The report also projected that cereal yields in seasonally dry and tropical regions such as India, are likely to decrease for even small local temperature rises (1-2 ^{o}C). Although increase in CO_2 is likely to be beneficial to several crops such as rice, wheat, and pulses, associated increase in temperatures, and increased variability of rainfall would considerably impact food production. Without direct CO_2 effect on crop yields, world cereal production is reduced by 11 to 20 per cent, and their inclusion brings yield decreases to between 1 and 8 per cent. Price increases resulting from climate-induced decreases in yield are estimated to range between ~24-145 per cent. The number of people at risk of hunger is estimated at ~640 million or ~6 per cent of total population in 2060 (Rosensweig and Parry, 1994). Agriculture typically played a larger role in developing economies than in the developed world. The majority of agricultural workers belonged to poorer segments of the population (Food and Agricultural Organization: FAO, 2006).

Increase in CO_2 concentration to 550 ppm is expected to increase the yields of rice, wheat, legumes and oilseeds by 10-20 per cent; however an increase of 1 ^{o}C in temperature may reduce yields of wheat, soybean, mustard, groundnut, and potato by 3-7 per cent. Productivity of most of the crops will decrease marginally by 2020 while in 2100 it will be 10-40 per cent due to increase in temperature, rainfall variability, and decreases in irrigation water. The major impacts of climate change will be in rain fed agriculture or un-irrigated crops, which is cultivated nearby 60 per cent of crop land. A temperature rise of 0.5 ^{o}C in winter temperature is projected to reduce rain fed wheat yield by 0.45 tonnes per hectare (Lal *et al*., 1998). In India, substantial work has been done in last decade with an aim at understanding the nature and magnitude of change in yield of different crops due to possible climate change (Pathak *et al*., 2003; Selvaraju 2003; Kumar *et al*., 2004; Mall *et al*., 2006; Aggarwal, 2007). Being India's agriculture is most basically depending on monsoon from the time immemorial, any change in monsoon rainfall will drastically affect agriculture practices and its food grains. In the states of Jharkhand and chhatisgarh alone, rice production loss during severe droughts (about one year in five) about 40 per cent of total production, on an average, with an estimated value of $800 million (Pandey, 2007). Eastern parts of the country are predicted to be most impacted by increased temperatures and decreased radiation, resulting in relatively fewer grains and shorter grain filling durations (Ministry of Environment and Forest, MoEF (Updated), Govt. of India, 2012). In Rajasthan, a reduction in the yield of pearl millet by 10-15 per cent was estimated with a 2 ^{o}C rise in temperature. Agriculture will be worst affected as fertile areas of Indo-Gangetic plains of India are more vulnerable to inundation and salinization. Food production of the country should increase by 5 million metric tonnes per year to keep pace with population increase and ensure food security. For reducing the impact of climate change on agriculture careful management of resources like soil, water and biodiversity are required (Mahato, 2014). Recent studies (Rao *et al*., 2009; Rao and Gopakumar, 2011) emphasized the urgent need to adapt crop management, crop improvement and crop protection strategies in tune with projected climate change scenarios so as to mitigate the ill effects of weather aberrations and sustain agricultural production in ensuing decades as the changes in thermal and moisture regimes had resulted in climate shifts that directly or indirectly affected food grain and plantation crops to a large extent. The innovative agricultural practices and technologies can also play a role in climate mitigation and adaptation.

MATERIALS AND METHODS

CHAPTER 3

MATERIALS AND METHODS

3.1 Materials used

The monthly rainfall data from a well spread network of 316 rain gauge stations (Sontakke *et al*., 2008, Singh, 2013) were collected for studying rainfall trend across eleven zones of the country from Indian Institute of Tropical Meteorology (IITM), Pune. The 2.5 degree square grid isobaric level data for mean sea level pressure, tropospheric temperature, geopotential height, wind, precipitable water, and cloud cover from National Centers for Environmental Prediction/National Center for Atmospheric Research (NCEP/NCAR) reanalysis data were also collected from 1949 to 2014, published by Kalnay *et al*., 1996. Gaussian grid Surface Air Temperature (SAT) from NCEP/NCAR reanalysis data from 1949 to 2014 (Kalnay *et al*., 1996) was also collected. Data on 2.0 degree square grid Sea Surface Temperature (SST) from National Climate Data Center (NCDC) were collected. Monthly tele-connection indices like Nino temperature, Southern Oscillation Index (SOI), Arctic Oscillation (AO) were utilized for analysis purpose. Land use and land cover data across India for the period from 1880 to 2013 were obtained from IITM, Pune and Directorate of Economics and Statistics. Though a sparse resolution dataset, the NCEP/NCAR reanalysis data were being used widely by numerous researchers across the globe (Singh *et al.*, 2011; Bansod *et al*., 2012) because of its improved geographical coverage and near real time update of its dataset. In certain research areas where observational data are sparse or when knowledge of the state of the atmosphere on a uniform grid is required, it works as a bridge between the behavior of the complex real time climate system and research communities to draw an inference for better societal needs. It has, of course, a limited applicability on extreme event analysis as well as smaller spatial scale analysis due to its sparse resolution. There were, in general, three major changes in the observing system although the reanalysis system essentially remains unchanged. The first major change took place during 1948–1957 when the upper air network was being established; second during 1958–1978 when modern global radiosonde network established, and the third in 1979 when the global operational use of satellite observing system was introduced (Kistler *et al*., 2001). Nathan *et al*. (2003) had also shown that the results based on the NCEP/NCAR reanalysis were more consistent with those derived data sets like HadSLP (Basnett and Parker, 1997) and the Trenberth (Trenberth and Paolino, 1980) data set when only the Northern Hemisphere data were used. The data based on the NCEP/NCAR reanalysis data were strongly influenced by observed data and hence classified as “Class A” (Kalnay *et al*., 1996).

3.1.1 Softwares used

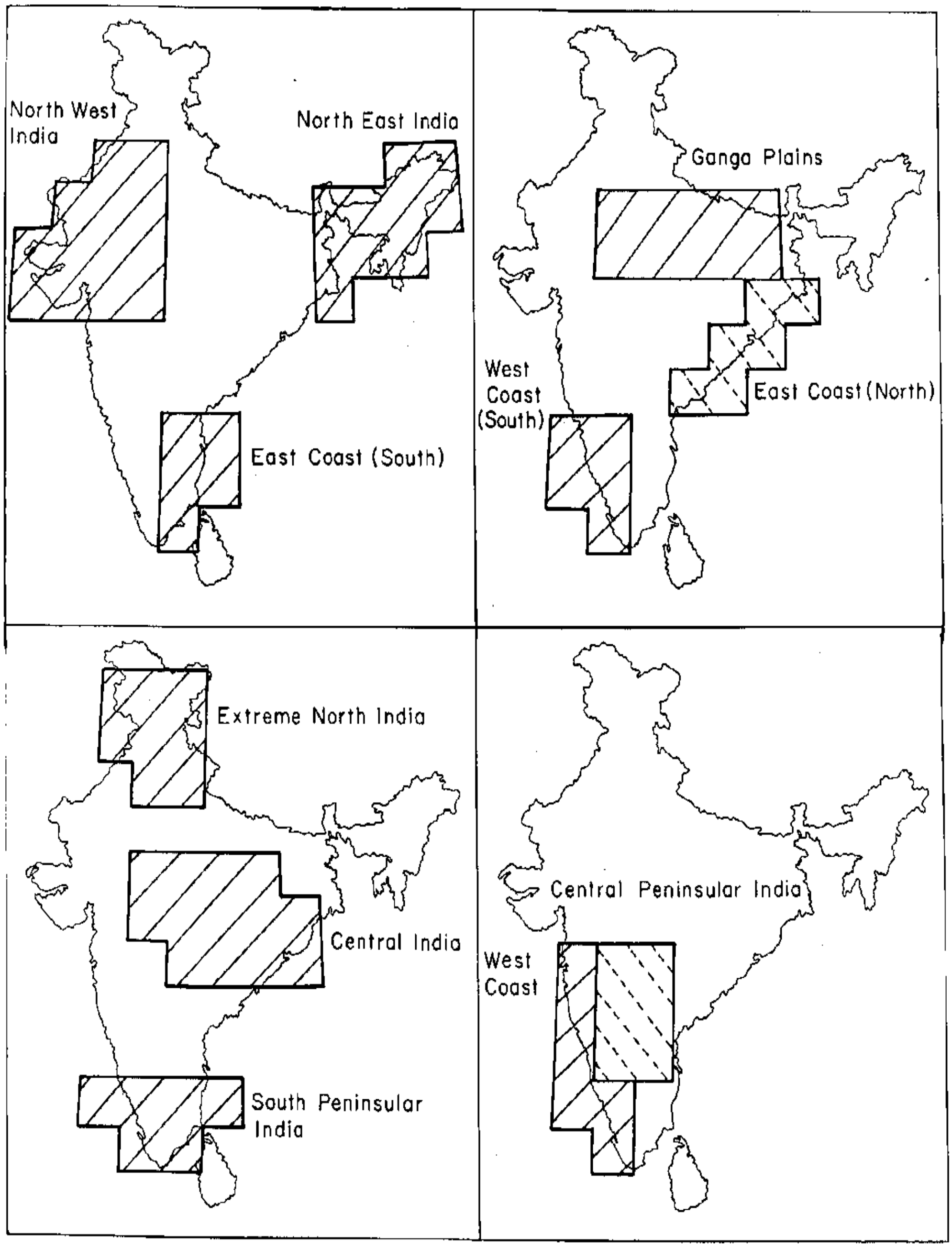
- Grid Analysis and Display System (GrADS)
- Origin 7.0
- Arc GIS 9.1
- Microsoft Office Excel

3.2 Methodology

The methods used are described objective- wise under various sub-heads as follows:

3.2.1 Rainfall variability and its causes

Rainfall is the most highly variable meteorological parameter and on all India rainfall series, it has some limitations (Singh, 2013). Keeping this in mind, the study was focused on the spatio-temporal variability over different zones of India (Fig. 1). The whole country had been demarcated into 11 zones of India, namely Extreme North India or North Mountainous India (NMI), North West India (NWI), North Central India (NCI), Ganga Plains (GP), Central Peninsular India (CPI), North East India (NEI), West Coast (WC), West Coast South (WC(S)), East Coast North (EC(N)), East Coast South (EC(S)) and South Peninsular India (SPI) based on the subjective considerations like spatio-temporal variation in rainfall, orographic effects, drainage pattern, physiography, continentality, oceanic influence, rain-shadow effect, rainfall regime, rain inducing disturbances, tropical-extra-tropical interaction, large-scale subsidence motion associated with remote and organized rising motion of a region led to demarcate different zones of India (Singh, 2004). The rainfall data for these 11 zones were available up to 2005. These zones had been used to examine the monthly, seasonal and annual variability of rainfall and other meteorological parameters. GIS is used as the tool for the analysis of the spatial distribution of rainfall. The map of India 'Administrative' on '*Conical Equal Area Projection with two Standard Parallels,* 15°N and 30°N ' projection system and 1:6 M scale showing the international boundary as well as the boundaries of the states prepared by the National Atlas and Thematic Mapping Organization (NATMO, 1986) had been traced on tracing paper and then scanned it so as to get the digitized map. The scanned image of this traced map of the physiographic regions had been geo-referenced and digitized through the state-of-the-art ArcGis 9.1 software environment for its use in this study. Geo-referencing started with four corners of the map and gradually approached towards the centre of the map so as to minimize the root mean square error (RMSE). The total numbers of ground truth points taken for this purpose were 31 for the whole country. The RMSE thus obtained in the whole process was 0.00085 errors which was acceptable for rectification. The whole processes were carried out with the Geographic Co-ordinate system (GCS). The projection system used in this study was WGS-1984 (Decimal degree). In GIS environment geo-database, the digitized polygon features created to organize different data layers which included (i) all India showing international boundary (ii) different states (Fig. 2). The station wise annual, seasonal and monsoon monthly rainfall data had been brought into this environment and made a database through their co-ordinate systems for further analysis. The station dataset had been rasterized using the in-built interpolation based on the ordinary kriging method interpolation with its spherical semivariogram. The pixel size of the rasterized field had been fixed as 0.001 with its maximum search radius of six units and 12 as the number of points to be considered. In this practice, islands were completely excluded. The rainfall



(Source: Singh, 2004)

Fig. 1. Map showing different zones of India

data were imported in the medium and interpolated the data using spatial analysis.

The schematic diagram of the whole process was given in Fig. 3. To understand the nature of the spatial variation of the rainfall across the country, monthly, seasonal [Winter (JF): Jan-Feb; Summer (MAM): Mar-April-May; Summer Monsoon (JJAS): Jun-Jul-Aug-Sep; Post-monsoon (OND): Oct-Nov-Dec] and annual rainfall data for 316 well spread stations over the country for the period from 1949 to 2005 were used in this study. Using the mean iso-hyetal annual, seasonal and monsoon monthly rainfall chart, the geographical area of the country have been classified into five rainfall zones viz., Very dry (VD), Dry (D), Normal (N), Wet (W) and Very wet (VW) with the help of the four partitioned values on the mean rainfall series viz., 20th percentile, 40th percentile, 60th percentile and 80th percentile and as follows:

Very dry : Less than or equal to the 20th percentile

Dry : More than the 20th percentile but less than or equal to 40th percentile.

Normal : More than the 40th percentile but less than or equal to 60th percentile.

Wet : More than the 60th percentile but less than or equal to 80th percentile.

Very wet : More than or equal to the 80th percentile

Thematic maps under five different rainfall zones (Very Dry, Dry, Normal, Wet, and Very Wet) had been prepared for winter, summer, summer monsoon, post monsoon and annual as well as for the monsoon months (June, July, August, September). The geographical area under each theme was also computed.

Various 2.5° x 2.5° gridded data meteorological parameters like mean sea level pressure (MSLP), surface air temperature (SAT), isobaric level tropospheric temperature (TT), isobaric level geopotential height (GPH), isobaric level zonal and meridional wind, precipitable water (PW), and

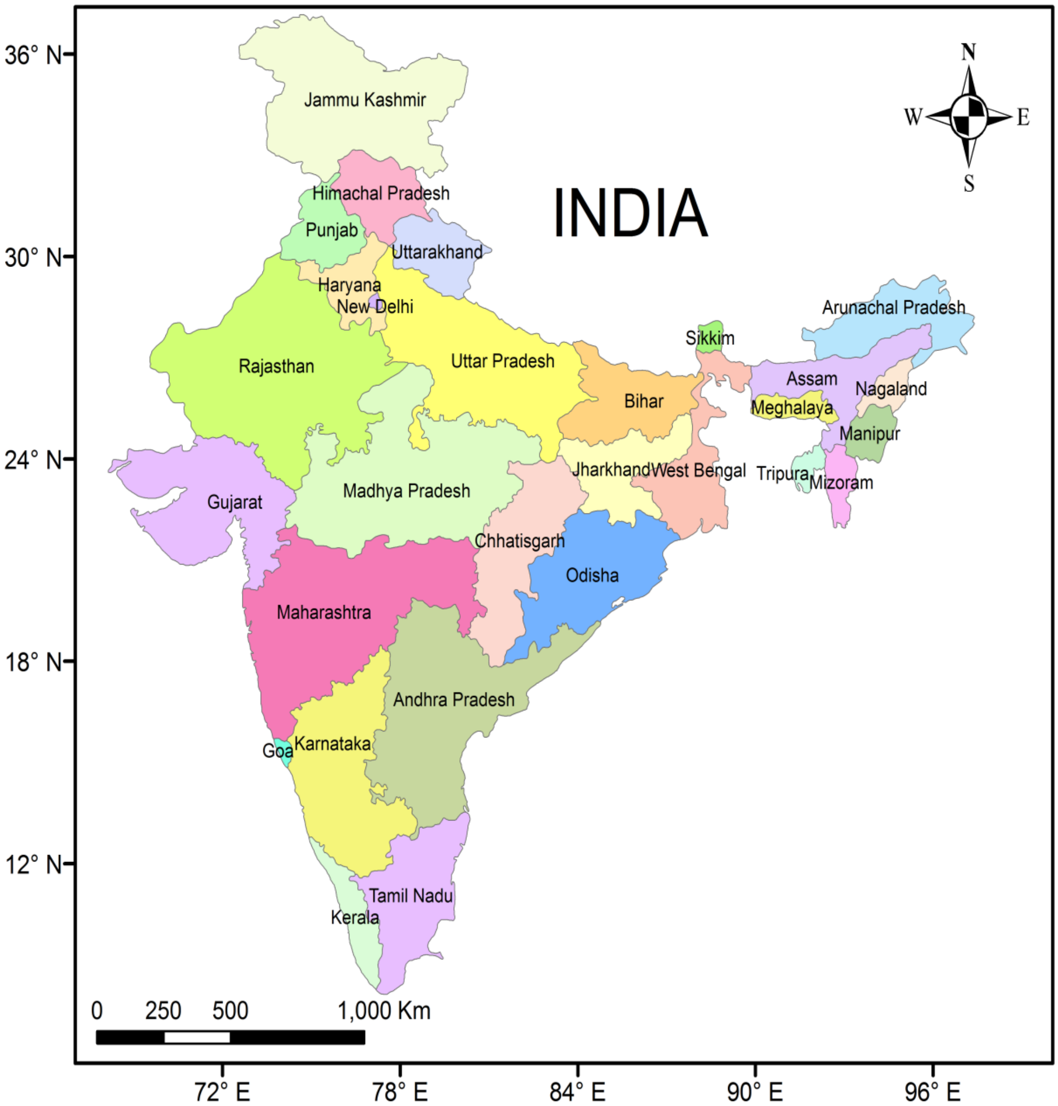


Fig. 2. Digitized map of India

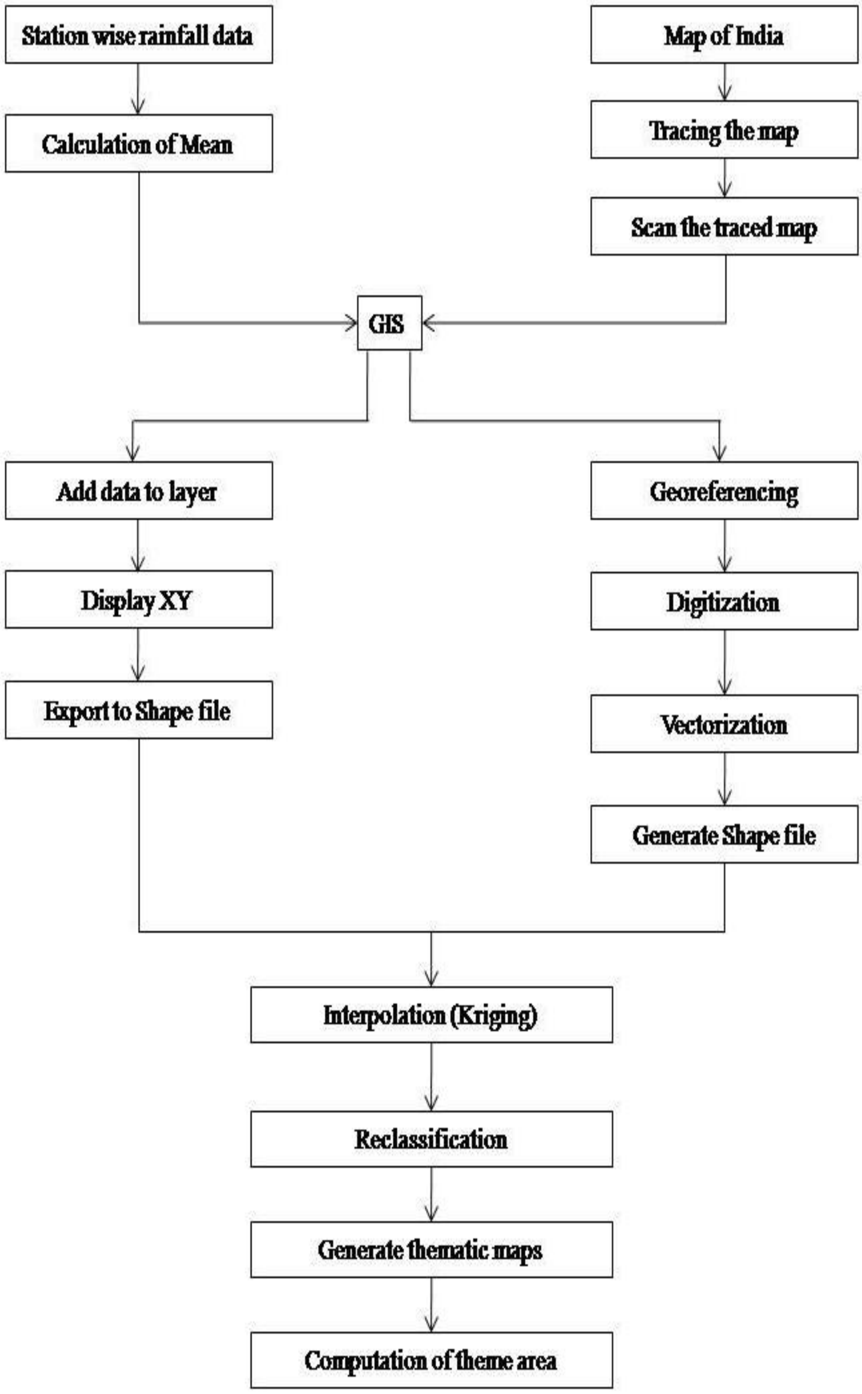


Fig. 3. Schematic diagram of spatial analysis of rainfall data using GIS

total cloud cover (CC) were downloaded from the NCEP/NCAR reanalysis data for the period from 1949 to 2014 (http://iridl.ldeo.columbia.edu). The 2.0 degree square grid Sea Surface Temperature (SST) data from the National Climate Data Center (NCDC) was also downloaded for this study. The isobaric level datasets had been rearranged in two layers as lower troposphere (925-500 hPa) and upper troposphere (500-200 hPa). In case of temperature, analysis for the full tropospheric temperature (925-200 hPa) had also been carried out. Keeping the role of the meteorological parameters to the Asia-India monsoon system in general and spatio-temporal rainfall variability over India, in particular, the global pattern of the various meteorological parameters had been examined. Considering the climate shift during the year 1978-79, the whole period had been divided into two parts, viz, (i) 1949-1978 (first half) and (ii) 1979-2014 (second half) to see the changes taken place on the meteorological parameters before and after the climate shift. This is also known as pre-climate and post-climate shift.

All the monthly, seasonal [Winter (JF): Jan-Feb; Summer (MAM): Mar-April-May; Summer Monsoon (JJAS): Jun-Jul-Aug-Sep; Post-monsoon (OND): Oct-Nov-Dec] and annual data at each isobaric level, lower and upper tropospheric layers for all the parameters had been examined. The spatial plot of the mean, anomaly and change (2^{nd} half-1^{st} half) for the parameters had been plotted to examine their variability. In this study, more emphasis had been given on monsoon monthly, monsoon seasonal and annual rainfall. Further, the behaviors of different parameters during the good and bad monsoon years had been examined. Based on amount of rainfall ten good and ten bad monsoon years had been selected. All these spatial variability analyses on different parameters had been carried out by using the Linux based free software called GrADS (Grid Analysis Display System). The Monthly tele-connection indices like Nino temperature, Southern Oscillation Index (SOI), Arctic Oscillation (AO) had also been examined in this study to its possible impact on Indian monsoon. In order to study the relationship between the different parameters and the ISMR and to explore the possible physical linkage between them, the simple linear correlation analysis was performed. This study also included the time series and trend analysis by examining the actual and the 9-point Gaussian low-pass filtered value plots and the Cramer's t_k statistic applied on 31-term running means of various meteorological parameters.

3.2.1.1 Gaussian 9-point filter analysis

The Gaussian 9-point filter is one of the most common forms of linear filtering. It is a smoothing symmetric function used in mathematical analysis. It is a non-uniform low pass filter used 9 sets of values. The central co-efficient diminishes with increasing distance from the centre. Thus the central value has a highest weighting factor than those on the either sides. These coefficients were based on the binomial coefficients. It is a different form of 9-point moving average where same weights are assigned to each entry. Being assigned equal weights to each entry, we lose the first four and last four averaged values. However, in case of this non-uniform low pass Gaussian 9-point filter, each of the entries could be smoothed with different weights. The computational procedures of these weights were excluded from my study as it had been used as standard weights in many earlier studies. These standard weights, derived from the binomial expansion, used in this filtering process were as under -

$$P_1 = 0.37*X_1+0.317*X_2+0.198*X_3+0.088*X_4+0.026*X_5$$

$$P_2 = 0.281*X_2+0.241*(X_1+X_3) +0.151*X_4+0.067*X_5+0.019*X_6$$

$$P_3 = 0.244*X_3+0.209*(X_2+X_4) +0.131*(X_1+X_5) +0.058*X_6+0.017*X_7$$

$$P_4 = 0.231*X_4+0.198*(X_3+X_5) +0.124*(X_2+X_6) +0.055*(X_1+X_7) +0.016*X_8$$

$$P_5 = 0.22*X_5+0.2*(X_6+X_4) +0.12*(X_7+X_3) +0.05*(X_8+X_2) +0.02*(X_9+X_1)$$

and so on …..

Where,

$P_{1, 2,\ldots, N}$ = Gaussian values assigned to the points

$X_{1, 2,\ldots, N}$ = Value of the parameter

Being it was symmetric to the centre (i.e. the 5th entry), the last four had been applied as that of the first four but in the reverse order. The other Gaussian values were applied the same weights as in the 5th entry.

Though most of the meteorological parameters do change abruptly and frequently, they do have a long term cumulative impact on atmosphere when considered for climate change. The Gaussian 9-point low pass filtered values will average out the highest and lowest values giving the smooth variation or fluctuation of the parameter. This type of filtering is important on climate change studies but not for extreme event analysis.

3.2.1.2 Cramer's t_k test

The comparison of the composite means corresponding to the various meteorological parameters with their long term averages had been made by means of the Cramer's t_k test based on the null hypothesis that "there is no significant difference between a composite mean of the parameter and the long term average of the whole period". The Cramer's t_k test statistic is distributed as the Student's t distribution with N-2 degrees of freedom. The null hypothesis is being tested with the two-tailed test for large values of $|t_k|$. The Cramer's t_k test statistic can be computed as

$$t_k = \tau_k \sqrt{\frac{n(N-2)}{(N-n-n\tau_k^2)}}$$

Where,

Long term average, $\overline{P} = \frac{1}{N}\sum_{i=1}^{N} P_i$

Composite mean of the individual period with n years, $\overline{P}_k = \frac{1}{n}\sum_{i-1}^{n} P_i$

Standard deviation of the entire period with N years, $\sigma = \sqrt{\sum_{i=1}^{N} \frac{(P_i - \overline{P})}{N}}$

Normalized anomaly, $\tau_k = \frac{\overline{P}_k - \overline{P}}{\sigma}$

3.2.2 Land use and land cover changes

Land cover is the observed (bio) physical cover on the earth's surface. Land cover data documents how much of a region is covered by forests, wetlands, impervious surfaces, agriculture, and other land and water types. Land use shows how people use the landscape – whether for development, conservation, or mixed uses. The land use and land cover data across India for the period from 1880 to 1980 which was documented under the research program of the American Institute of Indian Studies have been used in this study. This data is readily available at IITM, Pune. The data from 1980 to 2013 was taken from Directorate of Economics and Statistics. The data of area under wetland has taken from National Wetland Atlas. Various categories under land use and land cover data are net cultivable area, built up, forest, intermittent wood, grasslands, and barren land (desert). Decadal analysis has been applied to see the quantum of changes in the land use and land cover data over India as well as different states from 1900 to 2013. Recent changes in land use and land cover data for the period 2000 to 2013 also computed.

3.2.3 Climate change on environmental process

The analysis of meteorological parameters like global tropospheric temperature and surface air temperature, all India mean monthly temperature and the zonal wise rainfall trends were carried out using the graphical techniques based on the data collected from various sources (IMD, IITM, NCEP/NCAR and Institute of Tibetan Plateau Research) to understand the variations which are likely due to global warming and climate change and vice versa. Land use and land cover data were taken into account for analysis to understand the impact of climate change on environmental processes and vice versa, quoting the examples of changes in barren land, desert, forest cover, built up, and glaciers.

RESULTS AND DISCUSSION

CHAPTER 4
RESULTS AND DISCUSSION

The results are explained in the following section.

4.1 Analysis of all India rainfall

The mean all India rainfall and its temporal-spatial variability are presented in this section.

4.1.2 All India rainfall

The mean annual rainfall in India during 1949-2014 is 1167.5 mm with the standard deviation of 106.8 mm. The all India rainfall is very stable as the coefficient of variation is 9.1 per cent only. The seasonal rainfall during the monsoon period over India commencing from June and ending in September was 878.4 mm with the standard deviation of 88.1 mm, contributing 75.2 per cent to the mean annual rainfall (Table 1). The post-monsoon season rainfall is 120.7 mm, contributing 10.3 per cent to the mean annual rainfall, followed by summer (128.3 mm) which contributed 11.0 per cent to the annual. The all India rainfall during peak winter, commencing from January and ending in February, contributed only 40.2 mm with the standard deviation of 13.3 mm which was highly undependable as the coefficient of variability is also high (33.1 %).

The monthly all India rainfall indicated that July is the rainiest month (284.8 mm), followed by August (257.7 mm), September (170.7 mm) and June (165.2 mm). The coefficient of variation of monthly rainfall ranges from 12.8 per cent in August to 20.7 per cent in September, indicating that the monthly rainfall in all the four monsoon months is relatively stable (Table 2). December recorded the lowest (15.6 mm) rainfall, followed by January (17.3 mm), February (22.9 mm), March (28.5 mm), November (29.0 mm), and April (37.4 mm). The mean rainfall is intermediary in May (62.4 mm) and October (76.1 mm). The coefficient of variation is more than 50 per cent during November (52.4 %) and December (60.3%), indicating that the monthly rainfall during the above months is highly undependable unlike during the monsoon months.

Table 1. Seasonal and annual all India rainfall (mm)

Seasons	All India rainfall (mm)			
	Mean (mm) for whole period	Standard deviation	CV (%)	Percentage contribution to annual
Summer	128.3	20.6	16.1	11.0
Monsoon	878.4	88.1	10.0	75.2
Post-monsoon	120.7	29.4	24.3	10.3
Winter	40.2	13.3	33.1	3.4
Annual	1167.5	106.8	9.1	--

Table 2. Monthly rainfall variability

Months	All India rainfall (mm)			
	Mean (mm) for whole period	Standard deviation	C.V (%)	Percentage contribution to annual
January	17.3	7.9	45.6	1.5
February	22.9	10.0	43.7	2.0
March	28.5	11.4	40.0	2.4
April	37.4	10.0	26.7	3.2
May	62.4	14.1	22.6	5.3
June	165.2	30.7	18.6	14.1
July	284.8	39.5	13.9	24.4
August	257.7	33.0	12.8	22.1
September	170.7	35.4	20.7	14.6
October	76.1	27.6	36.3	6.5
November	29.0	15.2	52.4	2.5
December	15.6	9.4	60.3	1.3
Annual	1167.5	109.2	9.4	--

The coefficient of variation is intermediary during January (48.4 %) to April (26.7 %) due to receipt of summer and pre-monsoon rains across the country. It revealed that the mean all India seasonal rainfall is maximum during the southwest monsoon and minimum during the summer and it is intermediary during winter. It also indicated that July is the rainiest month and very low rainfall is received during December and January. It is also understood that the monsoon rainfall is relatively dependable and not so in other months outside the monsoon period.

There was a decline (32.7 mm) in all India annual rainfall from pre-climate shift period (1949-78) to post-climate shift period (1979-2014) when the year 1978 was considered as the climate shift year (Table 3). A significant decline (35.5 mm) was noticed during the monsoon period between pre-and-post climate shift periods while the decline was minimal (5.1 mm) during post-monsoon rainfall. Interestingly, there was increase in summer (3.6 mm) and peak winter rainfall (4.4 mm) between pre-and-post climate shift periods. When the monthly shifts were considered it was indicated that the decline in rainfall during July was the maximum (17.2 mm), followed by August (12.3 mm), September (9.4 mm) and October (9.1 mm). In contrast, marginal increase in rainfall was noticed in all the months, commencing from November to June, except December (Table 4). Interestingly, rainfall during June within the monsoon period showed an increase of 3.6 mm. The study revealed that there was a decline in rainfall during July, August, September, October, and December in post-climate shift period while increase in remaining months. However, the marginal increase in rainfall other than monsoon period might not compensate the decline in monsoon season since the contribution from the above season is much higher when compared to that of other season’s contribution to all India rainfall.

Table 3. Seasonal rainfall variability before and after climate shift (1978)

Seasons	All India Rainfall (mm)			
	Mean (1949-1978)	Mean (1949-2014	Change	Percentage increase or decrease
Summer	126.8	130.4	3.6	2.8
Monsoon	900.9	865.4	-35.5	3.9
Post-monsoon	123.9	118.8	-5.1	4.1
Winter	38.0	42.3	4.3	11.3
Annual	1189.6	1156.9	-32.7	2.7

Table 4. Monthly rainfall variability before and after climate shift (1978)

Months	All India Rainfall			
	Mean (1949-1978)	Mean (1949-2014	Change	Percentage increase or decrease
January	18.6	17.7	-0.9	-4.8
February	19.4	24.6	5.2	26.8
March	27.0	29.8	2.8	10.6
April	36.6	37.9	1.3	3.6
May	63.2	62.7	-0.6	-0.94
June	163.2	166.6	3.4	2.08
July	296.2	279.0	-17.2	-5.8
August	264.5	252.2	-12.3	-4.7
September	177.0	167.6	-9.4	-5.3
October	83.2	74.1	-9.1	-10.9
November	26.6	29.1	2.4	9.0
December	14.1	15.7	1.6	11.3
Annual	1189.6	1156.9	-32.7	-2.8

Considering limitations of the All India rainfall series due to its spatio-temporal variability, the spatio-temporal variability over the 11 zones of India, namely extreme north India, north west India, Ganga plains, central India, North East India, West Coast, West Coast (S), central peninsular India, East Coast (N), East Coast (S), and south peninsular India had also been examined. The details of its demarcation were given in earlier chapter (3.3). These zones were used to examine the monthly, seasonal and annual variability of rainfall and other meteorological parameters. The trends in all India rainfall indicated that the three zones viz., the East Coast (N), East Coast (S), and North East India showed increase in rainfall. In contrast, rainfall decline was noticed in all other zones across the country viz., Central Peninsular India, Ganga Plains, North Central India, North Mountainous India, North West India, South Peninsular India, West Coast (S), and West Coast (Fig. 4). The same trend was noticed for all India annual rainfall also. Similar trend was observed across the country in monsoon rainfall also (Fig.5). It is obvious that the bulk of annual rainfall depends on monsoonal rainfall.

The result is in agreement with the studies of Singh *et al*. (2005), Ranade *et al*. (2008), and Sontakke *et al*. (2008). According to the study during recent decades (1979–2011), the monsoon rainfall over India was less by 4.51 per cent compared to the period 1949–1978 (Ranade *et al*., 2008; Sontakke *et al*., 2008).

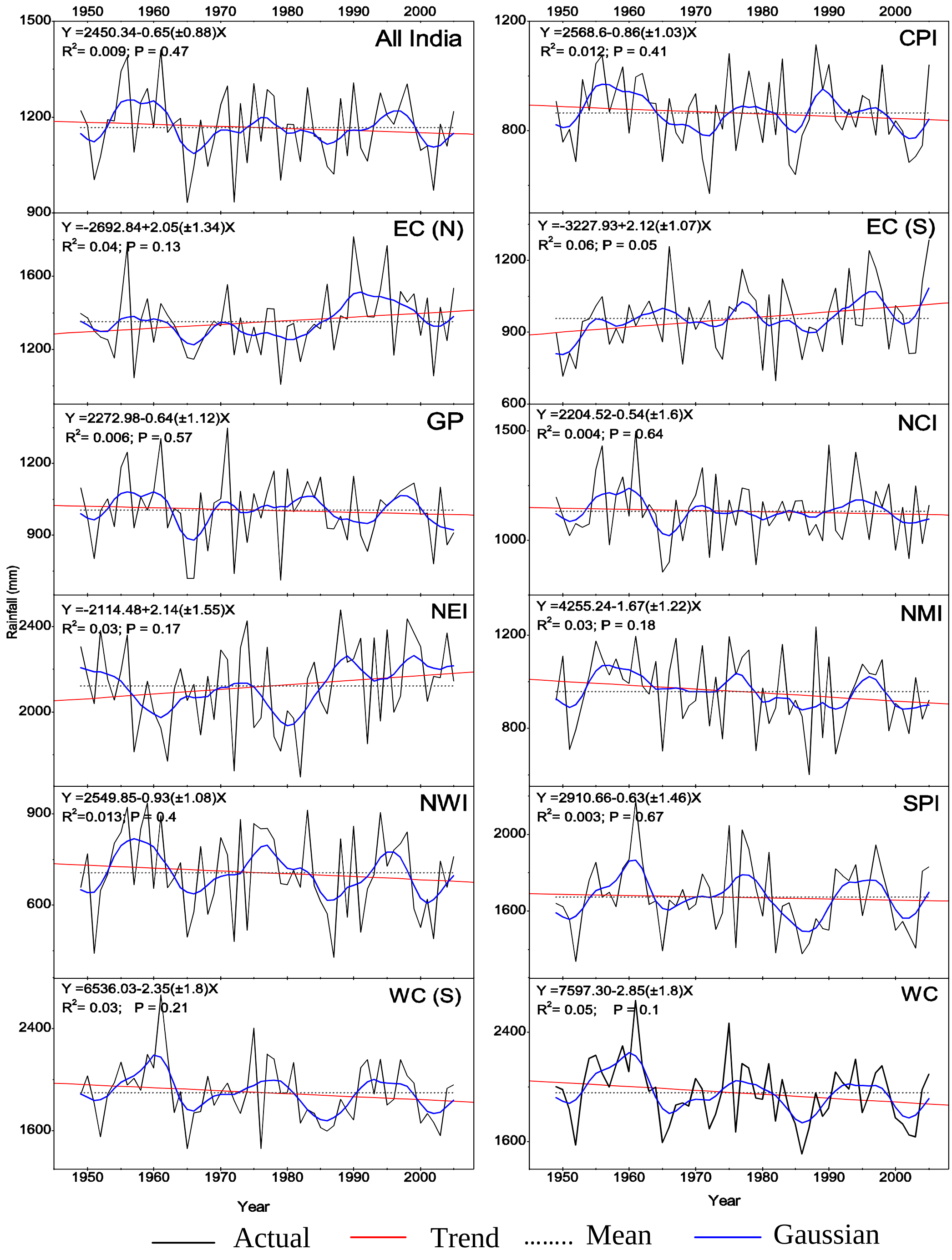


Fig. 4. Annual rainfall trend across the country from 1949 to 2005

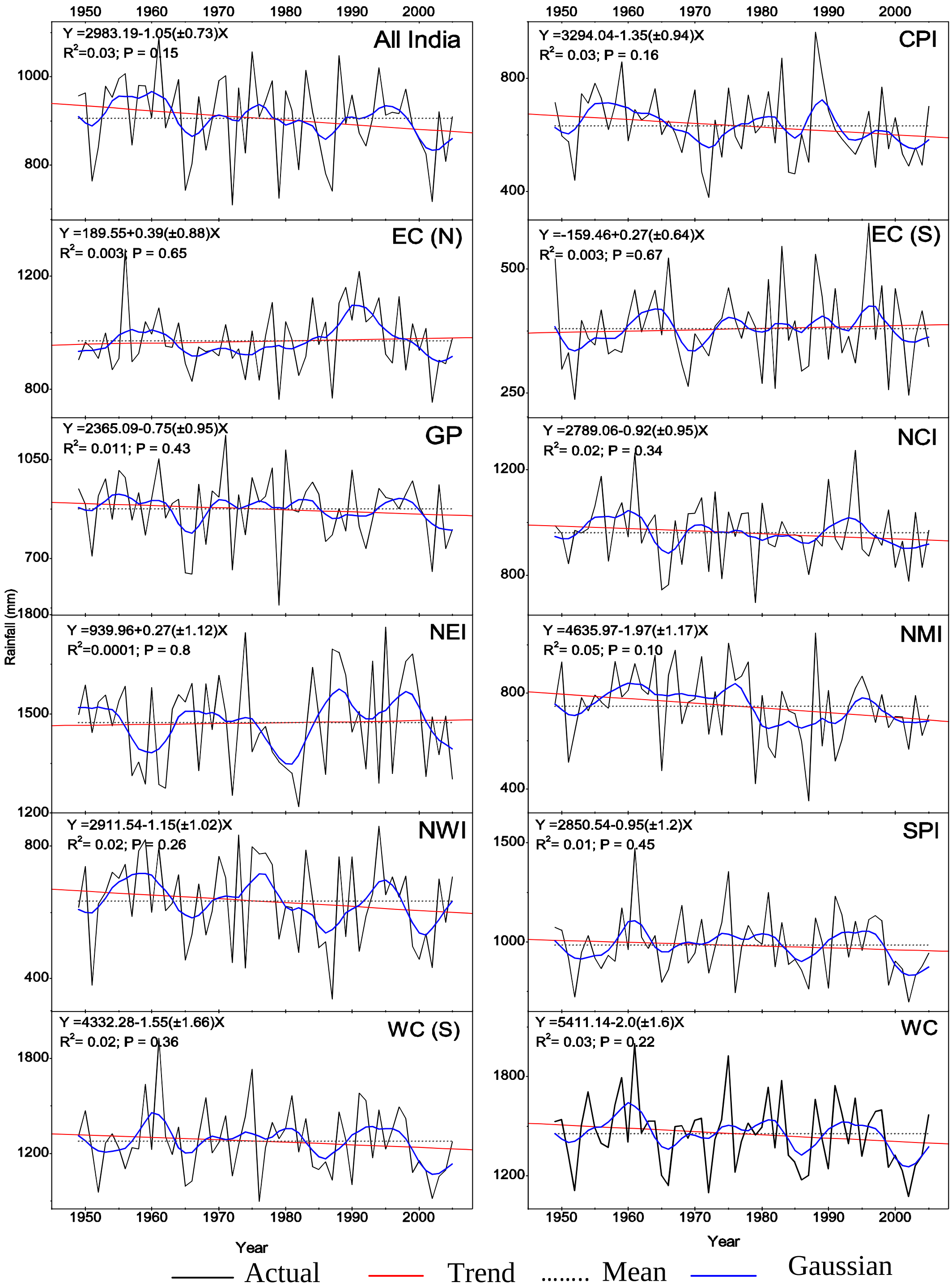


Fig. 5. Monsoon rainfall trend across the country from 1949 to 2005

4.1.2 Spatial variability analysis of rainfall using GIS

Five rainfall zones were demarcated such as very dry, dry, normal, wet, and very wet using the percentile rank method based on the mean rainfall of the country using GIS since the trend analysis did not give the spatial distribution. If the annual rainfall is less than or equal to 1076 mm at 20 per cent probability of mean annual rainfall, it was classified under the very dry zone (Table 5). If the annual rainfall varies between 1076.1 mm to 1143.2 mm at 40 per cent probability, it was classified as the dry zone. If the rainfall varies between 1143.3 mm and 1190.8 mm at 60 per cent probability level then the zone was classified as normal. The wet zone was classified if the annual rainfall falls between 1190.9 mm and 1240.9 mm at 80 per cent probability. The very wet zone was categorized at more than 80 per cent probability if the rainfall is greater than 1240.9 mm. From the mean annual rainfall only, the clear picture of rainfall distribution could not be identified. So, seasonal analysis is required. If the winter (JF) rainfall is less than or equal to 18.1 mm at 20 per cent probability of mean seasonal rainfall, it was classified under very dry zone. If the seasonal rainfall varies between 18.2 mm to 26.5 mm at 40 per cent probability, it was classified as dry zone. The normal zone was classified if the rainfall varies between 26.6 mm and 32.9 mm at 60 per cent probability level. The wet zone as if the seasonal rainfall falls between 33 mm and 41.8 mm at 80 per cent probability. The very wet zone was categorized at more than 80 per cent probability if the rainfall was greater than 41.8 mm. If the summer (MAM) rainfall is less than or equal to 82.5 mm at 20 per cent probability of mean seasonal rainfall, it was classified under very dry zone. If the seasonal rainfall varies between 82.6 mm to 92 mm at 40 per cent probability, it was classified as dry zone, while the normal zone if the rainfall varies between 92.1 mm and 105.9 mm at 60 per cent probability level.

Table 5. Classification of rainfall zones based on percentile rank method for annual and different seasons

Seasons	Rainfall in mm				
	Very dry (≤ 20 %)	Dry (21- ≤ 40%)	Normal (41- ≤ 60 %)	Wet (61- ≤ 80%)	Very wet (> 80%)
Annual	≤ 1076	1076.1-1143.2	1143.3-1190.8	1190.9-1240.9	> 1240.9
Winter	≤ 18.1	18.2-26.5	26.6-32.9	33-41.8	> 41.8
Summer	≤ 82.5	82.6-92	92.1-105.9	106-119.2	> 119.3
Monsoon	≤ 839.2	839.3-896	896.1-944.1	944.2-978.7	> 978.7
Post-monsoon	≤ 94.9	95-113.3	113.4-130.4	130.5-150.6	> 150.6

Table 6. Classification of rainfall zones based on percentile rank method for different monsoon months

Months	Rainfall in mm				
	Very Dry (≤ 20 %)	Dry (21 ≤ 40 %)	Normal (41 ≤ 60 %)	Wet (61 ≤ 80 %)	Very wet (> 80%)
Jun	≤ 140.4	140.5-162	162.1-178.5	178.6-210.1	> 210.1
Jul	≤ 270.5	270.6-290.9	291-310	310.1-328.3	> 328.3
Aug	≤ 228.2	228.3-249.1	249.2-278.4	278.5-294.8	> 294.8
Sep	≤ 134.7	134.8-160	160.1-185.5	185.6-213	> 213

(Jun – June, Jul – July, Aug – August, and Sep – September)

The zone was classified as wet if the seasonal rainfall falls between 106 mm and 119.2 mm at 80 per cent probability. The very wet zone was categorized at more than 80 per cent probability if the rainfall is greater than 119.3 mm. If the summer monsoon (JJAS) rainfall is less than or equal to 839.2 mm at 20 per cent probability of mean seasonal rainfall, it was classified under very dry zone. The zone was classified as dry if the seasonal rainfall varies between 839.3 mm to 896 mm at 40 per cent probability. The zone was categorized as normal if the rainfall varies between 896.1 mm and 944.1 mm at 60 per cent probability level. The wet zone as if the seasonal rainfall falls between 944.2 mm and 978.7 mm at 80 per cent probability. The zone was categorized as very wet at more than 80 per cent probability if the rainfall is greater than 978.7 mm. If the post monsoon (OND) rainfall is less than or equal to 94.9 mm at 20 per cent probability of mean seasonal rainfall, the zone was classified as very dry. If the seasonal rainfall varies between 95 mm to 113.3 mm at 40 per cent probability, the zone was classified as dry. The zone was classified as normal, if the rainfall ranges from 113.4.1 mm to 130.4 mm at 60 per cent probability level. The zone was classified as wet, if the seasonal rainfall ranges from 130.5 mm to 150.6 mm at 80 per cent probability. The zone was categorized as very wet at more than 80 per cent probability, if the rainfall is greater than 156.6 mm.

For getting more clarity about the rainfall, monthly analysis of monsoon season has been done. It is presented in Table 6. More than 70 per cent of annual rainfall is contributed from the monsoon months. So, the analyses of monsoon months carried out. If the monthly (June) rainfall is less than or equal to 140.4 mm at 20 per cent probability of mean monthly rainfall, the zone was classified as very dry. If the monthly rainfall varies between 140.5 mm to 162 mm at 40 per cent probability, the zone was classified as dry. The zone was classified as normal, if the rainfall varies between 162.1 mm and 178.5 mm at 60 per cent probability level. The zone was classified as wet, if the monthly rainfall ranges from 178.6 mm to 210.1 mm at 80 percent probability. The zone was categorized as very wet at more than 80 per cent probability, if the rainfall is greater than

210.1 mm. If the monthly (July) rainfall is less than or equal to 270.5 mm at 20 per cent probability of mean monthly rainfall, the zone was classified as very dry. The zone was classified as dry, if the monthly rainfall varies between 270.6 mm to 290.9 mm at 40 per cent probability. The zone was classified as normal, if the rainfall varies between 291 mm and 310 mm at 60 per cent probability level. The zone was classified as wet, if the monthly rainfall varies between 310.1 mm and 328.3 mm at 80 per cent probability. The zone was categorized as very wet at more than 80 per cent probability, if the rainfall is greater than 328.3 mm. If the monthly (August) rainfall is less than or equal to 228.2 mm at 20 per cent probability of mean monthly rainfall, the zone was classified as very dry. If the monthly rainfall varies between 228.3 mm to 249.1 mm at 40 per cent probability, the zone was classified as dry. The zone was classified as normal, if the rainfall varies between 249.2 mm and 278.4 mm at 60 per cent probability level. The zone was classified as wet, if the monthly rainfall ranges from 278.5 mm to 294.8 mm at 80 per cent probability. The zone was categorized as very wet at more than 80 per cent probability if the rainfall is greater than 294.8 mm. If the monthly (September) rainfall is less than or equal to 134.7 mm at 20 per cent probability of mean monthly rainfall, the zone was classified as very dry zone. If the monthly rainfall varies between 134.8 mm to 160 mm at 40 per cent probability, the zone was classified as dry. The zone was classified as normal, if the rainfall varies between 160.1 mm and 185.5 mm at 60 per cent probability level. The zone was classified as wet, if the monthly rainfall ranges from 185.6 mm to 213 mm at 80 per cent probability. The zone was categorized as very wet at more than 80 per cent probability if the rainfall is greater than 213 mm. Based on these values, thematic maps for different monsoon months, seasons and annual are prepared using GIS.

The spatial variability as well as its spatial coverage under each rainfall categories is represented in Table 7 and 8. In JF, an area of 1204398 km^2 contributed very dry zone whereas an area of 892249 km^2 was under very wet zone. The dry and wet zone was covered 365645 km^2 and 425144 km^2

respectively. The normal zone during this period was 410637 km^2. In annual, an area of 1475347 km^2 contributed under very dry zone whereas an area of 1423295 km^2 was under very wet zone. The dry and wet zone covered 183993 km^2 and 99676 km^2 respectively. The area spread under normal zone was 115556 km^2. In MAM, an area of 1926279 km^2 contributed under very dry zone whereas an area of 1085621 km^2 was under very wet zone. The dry and wet zone had covered 97309 km^2 and 69624 km^2 of area respectively. The normal zone was spread over an area of 119240 km^2. In JJAS, an area of 1309319 km^2 contributed very dry zone whereas an area of 1611841 km^2 was under very wet zone. The dry and wet zone was covered 133303 km^2 and 99259 km^2 respectively. The normal zone during this period was spread over 144351 km^2. In OND, an area of 1572662 km^2 contributed towards very dry zone whereas an area of 1188086 km^2 was under very wet zone. The dry and wet zone was covered 188005 km^2 and 174428 km^2 respectively. The normal zone during this period had an area of 174892 km^2.

In June, an area of 1373210 km^2 contributed very dry zone whereas an area of 1178556 km^2 was under very wet zone. The dry and wet zone covered 291262 km^2 and 294641 km^2 respectively. The normal zone during this period was less which covered an area around 160404 km^2. In July, an area of 1195768km^2 contributed towards very dry zone whereas an area of 1386708 km^2 was under very wet zone. The dry and wet zone was covered 181185 km^2 and 396419 km^2 respectively. The normal zone during this period was 137993 km^2 of the total geographical area. In August, an area of 1166083 km^2 contributed towards very dry zone whereas an area of 1616610 km^2 was under very wet zone. The dry and wet zone covered 177342 km^2 and 130489 km^2 respectively. The normal zone during this period was 207549 km^2. In September, an area of 587275 km^2 contributed under very dry zone whereas an area of 1210441 km^2 was under very wet zone. The dry and wet zone covered an area of 445923 km^2 and 569263 km^2 respectively. The normal zone during this period was spread over 485171 km^2 (Table 8).

Table 7. Area under different selected rainfall zones during annual and different seasons.

Seasons	Geographical area (km^2) of the country				
	Very Dry	Dry	Normal	Wet	Very Wet
ANN	1475347	183993	115556	99676	1423295
JF	1204398	365645	410637	425144	892249
MAM	1926279	97309	119240	69624	1085621
JJAS	1309319	133303	144351	99259	1611841
OND	1572662	188005	174892	174428	1188086

(ANN – Annual, JF – Winter, MAM – Summer, JJAS – Summer monsoon, OND – Post monsoon)

Table 8. Area under different selected rainfall zones during monsoon months

Months	Geographical area (km^2) of the country				
	Very Dry	Dry	Normal	Wet	Very Wet
Jun	1373210	291262	160404	294641	1178556
Jul	1195768	181185	137993	396419	1386708
Aug	1166083	177342	207549	130489	1616610
Sep	587275	445923	485171	569263	1210441

(Jun – June, Jul – July, Aug – August, and Sep – September)

Thematic maps prepared for monsoon months, different seasons and annual are presented in Fig. 6- 14.

4.1.2.1 Thematic map for the month of June

The geographical area under different rainfall zones computed through the mean monthly rainfall of June is shown in Fig. 6. Forty one per cent of the country was under very dry zone whereas thirty six per cent was under very wet zone. Area under very dry region extended from north western part of the country to southern peninsular India in a diagonal fashion while, area under very wet zone was observed in West Coast, North Mountainous India, North East India, and East Coast North. The dry and wet zone covered nine per cent each, of the total geographical area. The dry and wet zones were seen in Central India and Ganga Plains. The geographical extent of normal zone during this period was very less which covered five per cent of the total geographical area. Normal zone was seen in Central India, Ganga Plains, and east of West Coast.

4.1.2.2 Thematic map for the month of July

The geographical area under different rainfall zones computed through the mean monthly rainfall of July is shown in Fig. 7. Thirty six per cent of the country was under very dry zone; six per cent under dry zone; four per cent under normal zone; 12 per cent under wet zone and 42 per cent of area was under very wet zone. Area under very dry zone extended from southern peninsula to Central India, while in North West India it had shrunken than the month of June. Area under very wet zone was seen in west coast, North East India, North Mountainous India, and Ganga Plains. Wet zone was seen in East Coast North. Dry and normal zones are seen in Central India and east of West Coast.

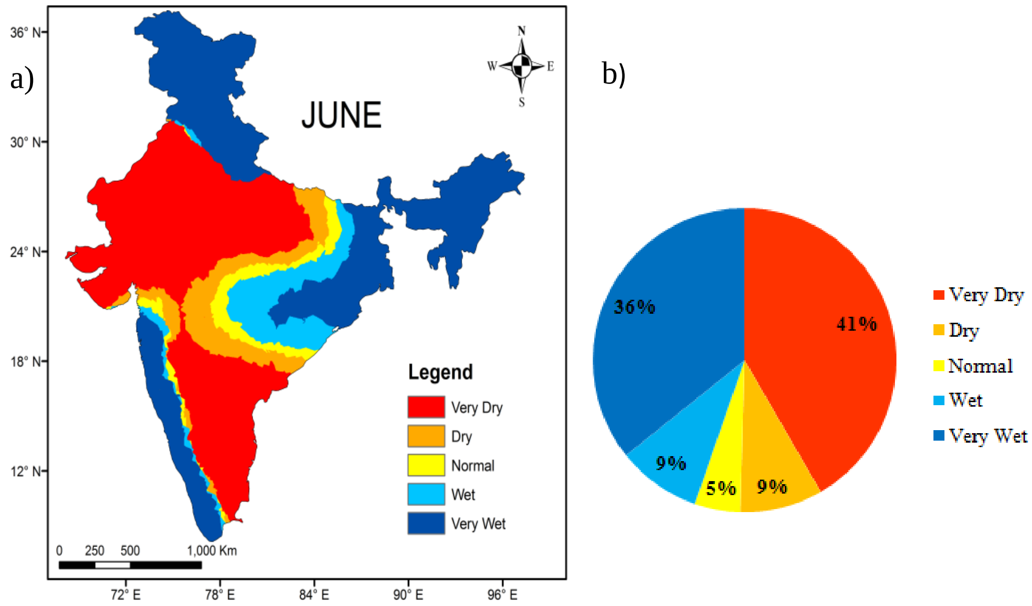


Fig. 6. (a) Spatial distribution of rainfall during June (b) Area under different zones during June

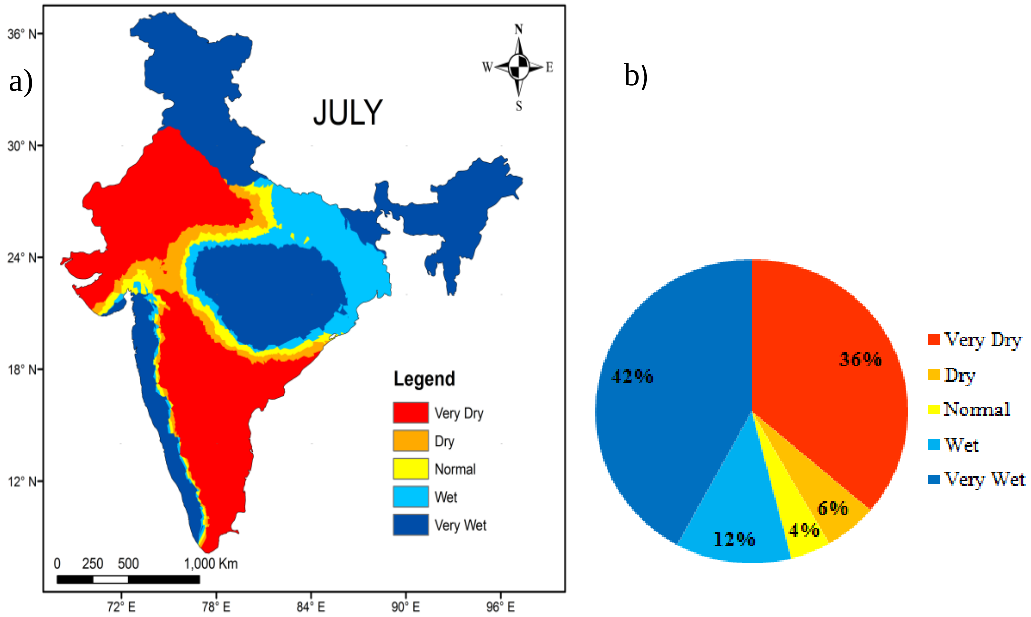


Fig. 7. (a) Spatial distribution of rainfall during July (b) Area under different zones during July

4.1.2.3 Thematic map for the month of August

The geographical area under different rainfall zones computed through the mean monthly rainfall of August is shown in Fig. 8. Thirty five per cent of the country was under very dry zone; six per cent under dry zone; six per cent under normal zone; four per cent under wet zone; and forty nine per cent of the country was under very wet zone. Most part of the Punjab, Haryana, Rajasthan, Gujarat, Maharashtra, Karnataka, Tamil Nadu, Telangana, and Andhra Pradesh experienced a very dry rainfall condition during the month of August whereas Jammu and Kashmir, Himachal Pradesh, Uttarakhand, Bihar, Jharkhand, Chhattisgarh, East Madhya Pradesh, West Bengal, and Northeastern states received very good amount of rainfall. Dry, wet and normal zones were seen in central India. It was also seen that very wet condition in west coast is replaced by normal condition.

4.1.2.4 Thematic map for the month of September

The geographical area under different rainfall zones computed through the mean monthly rainfall of September is shown in Fig. 9. Eighteen per cent of the country was under very dry zone; 13 per cent under dry zone; 15 per cent under normal zone; 17 per cent under wet zone. Major portion was under very wet zone which contributed 37 per cent of the total geographical area. Most part of the Punjab, Haryana, Rajasthan, Gujarat, and some pockets of Tamil Nadu and Karnataka experienced a very dry rainfall condition during the month of September whereas Jammu and Kashmir, Himachal Pradesh, Uttarakhand, Odisha, Jharkhand, West Bengal, and Northeastern states received good amount of rainfall. Entire West Coast region is transformed into wet to normal condition during the month of September. East Coast North and some parts of Ganga Plains experienced wet condition during September.

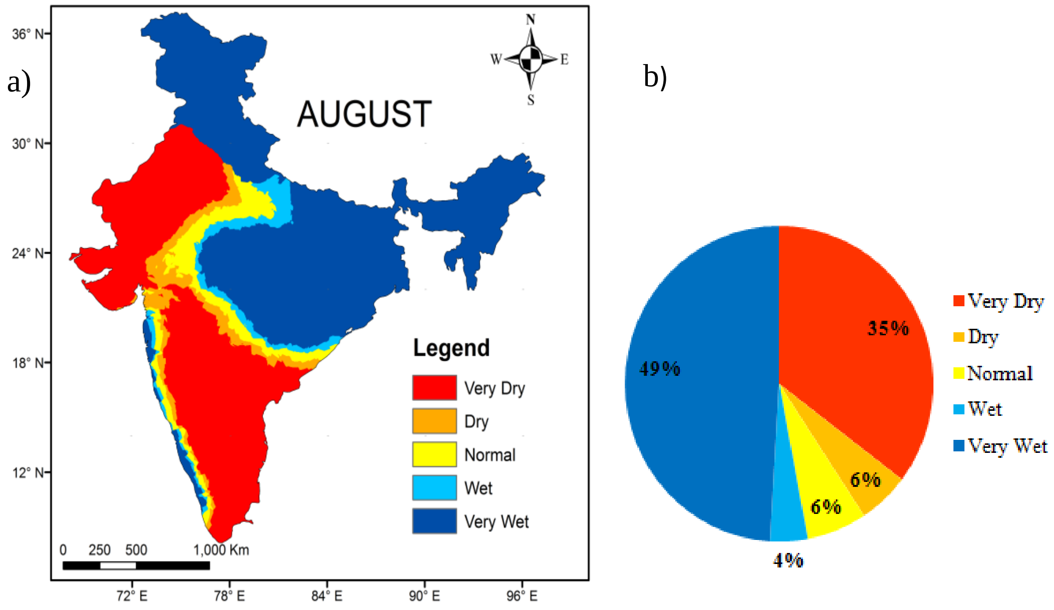


Fig. 8. (a) Spatial distribution of rainfall during August (b) Area under different zones for August

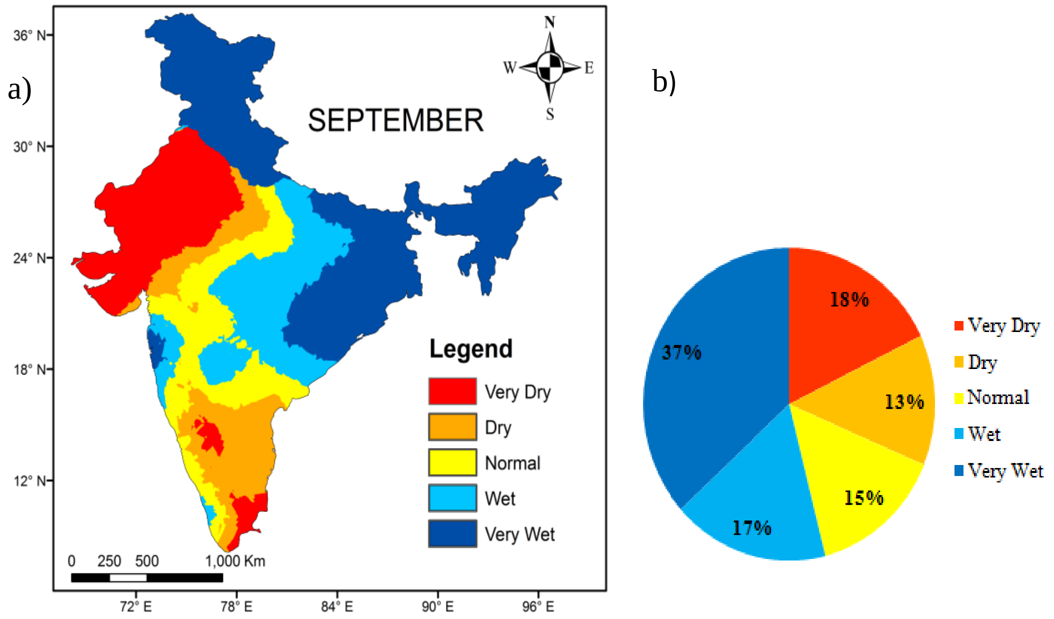


Fig. 9. (a) Spatial distribution of rainfall during September (b) Area under different zones for September

4.1.2.5 Thematic map for the winter season (JF)

The geographical area under different rainfall zones computed through the mean monthly rainfall of winter season is shown in Fig. 10. Thirty seven per cent of the country was under very dry zone; 11 per cent under dry zone; 12 per cent under normal zone; 13 per cent under wet zone and 27 per cent under very wet zone. Most part of the North West India, Maharashtra, Goa, Karnataka, Telangana, and Andhra Pradesh experienced a very dry rainfall condition during the winter season whereas Jammu and Kashmir, Himachal Pradesh, Uttarakhand, Eastern Central India, Southern peninsular India, Arunachal Pradesh, Nagaland, Manipur, Missoram, and Tripura received good amount of rainfall. Wet, dry, and normal zones were seen in North Central India, Ganga Plains, and south of the Southern Peninsula during summer season.

4.1.2.6 Thematic map for the summer season (MAM)

The geographical area under different rainfall zones computed through the mean monthly rainfall of summer season is shown in Fig. 11. Fifty eight per cent of the country was under very dry zone; three per cent under dry zone; four per cent under normal zone; two per cent under wet zone and 33 per cent was under very wet zone. Most part of the North West India, Madhya Pradesh, Chhattisgarh, Maharashtra, Uttar Pradesh, Bihar, Jharkhand, Goa, Karnataka, Telangana, Andhra Pradesh, and Tamil Nadu, experienced a very dry rainfall condition during the summer season whereas Jammu and Kashmir, Himachal Pradesh, Uttarakhand, Southern Peninsula, West Bengal, and North East India received good amount of rainfall. Wet, dry, and normal zones were seen in North Central India, Ganga Plains, and some pockets of Southern Peninsula during summer season.

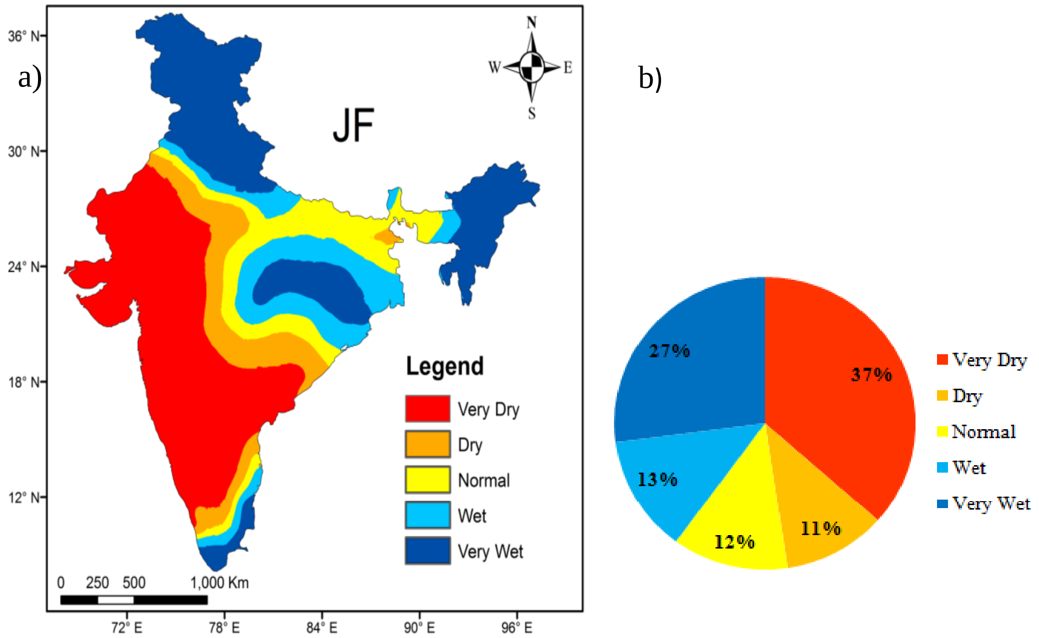


Fig. 10. (a) Spatial distribution of rainfall during winter season (JF) (b) Area under different zones for winter season

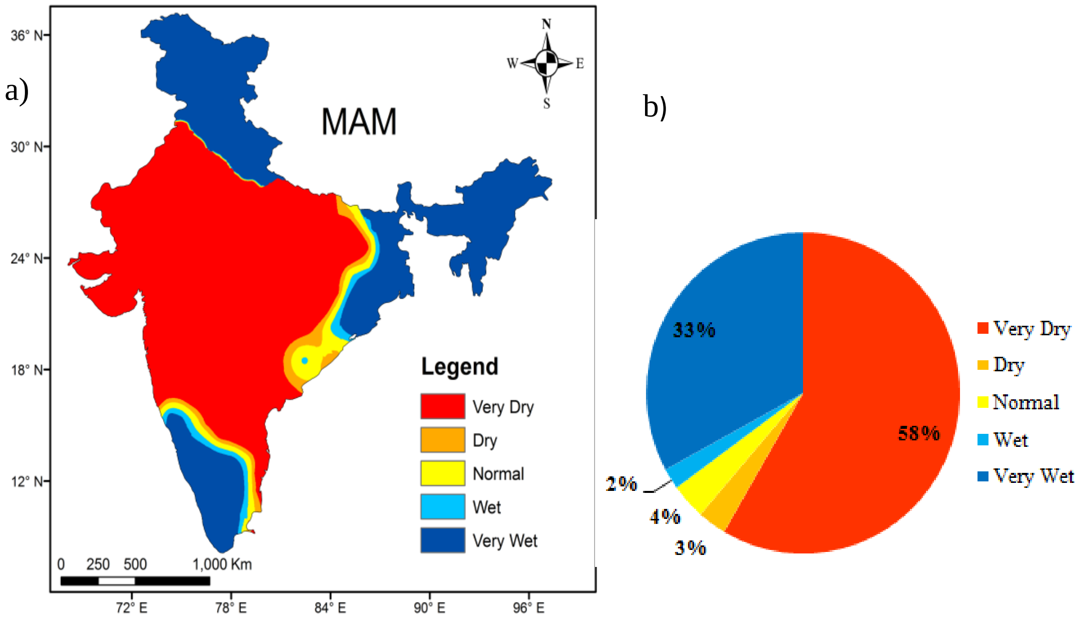


Fig. 11. (a) Spatial distribution of rainfall during summer season (MAM) (b) Area under different zones for summer season

4.1.2.7 Thematic map for the summer monsoon season (JJAS)

The geographical area under different rainfall zones computed through the mean monthly rainfall of summer monsoon is shown in Figure 12. Forty per cent of the country was under very dry zones; four per cent under dry zone; four per cent under normal zone; three per cent under wet zone and 49 per cent under very wet zone. Most part of the North West India to South Peninsula experienced a very dry rainfall condition during the summer monsoon season whereas West Coast, Jammu and Kashmir, Himachal Pradesh, Uttarakhand, Eastern Central India, and Northeastern states received good amount of rainfall. Wet, dry, and normal zones were seen in some pockets between North West India and North Central India. Same was observed in regions between west coast and south peninsular India during summer monsoon season.

4.1.2.8 Thematic map for the post-monsoon season (OND)

The geographical area under different rainfall zones computed through the mean monthly rainfall of post-monsoon season is shown in Fig. 13. Forty eight per cent of the country was under very dry zone; six per cent under dry zone; five per cent under normal zone; five per cent under wet zone and 36 per cent under very wet zone. Most part of the North West India and North Central India experienced a very dry rainfall condition during the post-monsoon season whereas Southern Peninsular India, North Mountainous India, and North East India received good amount of rainfall. Wet, normal, and dry zones were in between very dry and very wet zones all over India.

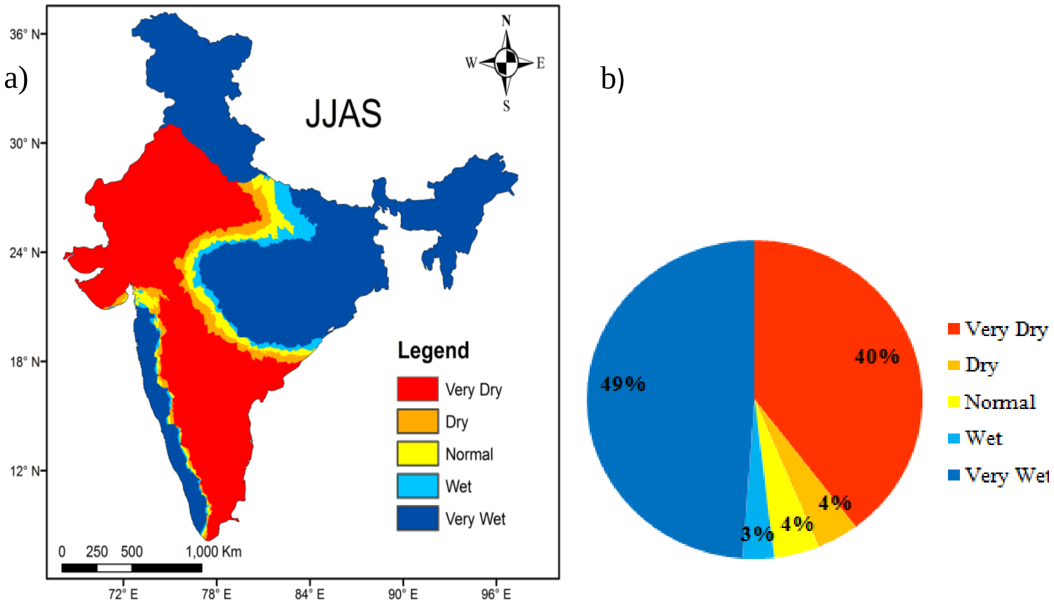


Fig. 12. (a) Spatial distribution of rainfall during summer monsoon season (JJAS) (b) Area under different zones for summer monsoon season

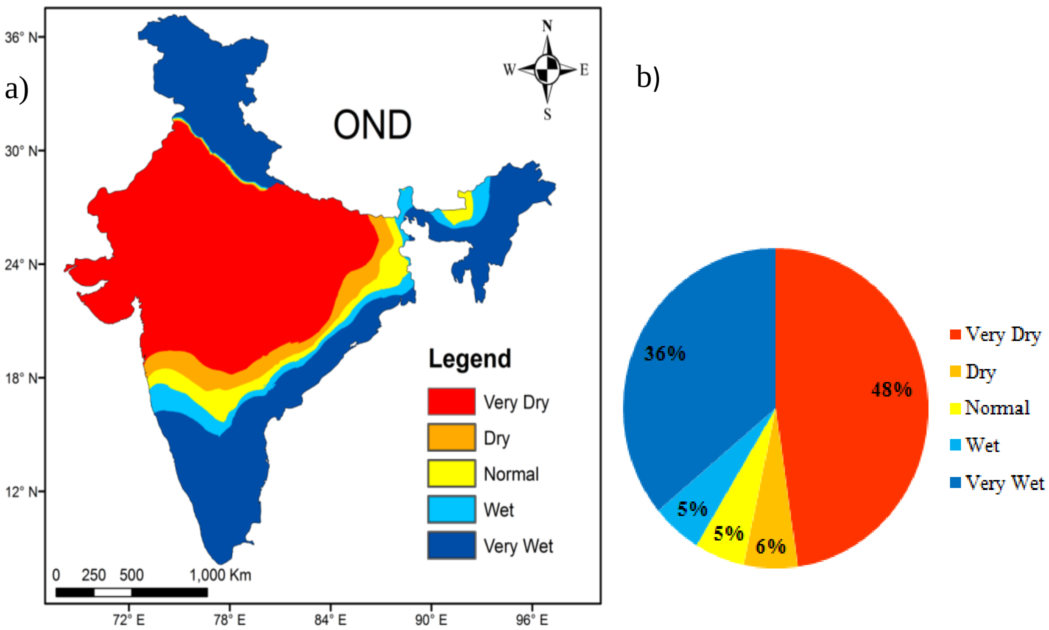


Fig. 13. (a) Spatial distribution of rainfall during post-monsoon season (OND) (b) Area under different zones for post-monsoon season

4.1.2.9 Spatial distribution of annual rainfall

The geographical area under different themes computed through the mean monthly rainfall for annual is shown in Fig. 14. Forty five per cent of the country was under very dry condition; six per cent under dry condition; three per cent for normal condition; three per cent for wet condition and 43 per cent under very wet condition (Fig.14). Most part of the North West India, North Central India, Ganga Plains, and Southern Peninsula India experienced a very dry rainfall condition during the annual rainfall condition whereas West Coast, North Mountainous India, and Eastern regions of India received good amount of rainfall. Wet, normal, and dry regions were seen in between very dry and very wet zones of West Coast and East Coast North.

During the month of June, the spatial coverage under very dry condition is more than that of the very wet condition because the summer monsoon is yet to become active. The area under very dry condition was found to be decreased from June to September. As the monsoon progressed, the spatial area under wet and very wet conditions started expanding with the shrinking of dry and very dry areas. During August, the spatial coverage under very wet condition was extended from foothills of Himalaya to North Eastern states. The West coast of India experienced a reduction in area under very wet condition during July. The areas under very dry and very wet conditions reduced during September compared to that of August. Majority of the geographical area of the country were coming under dry and very dry conditions during all the seasons except summer monsoon season. The geographical areas under different rainfall conditions demarcated through this study will be highly useful for the society.

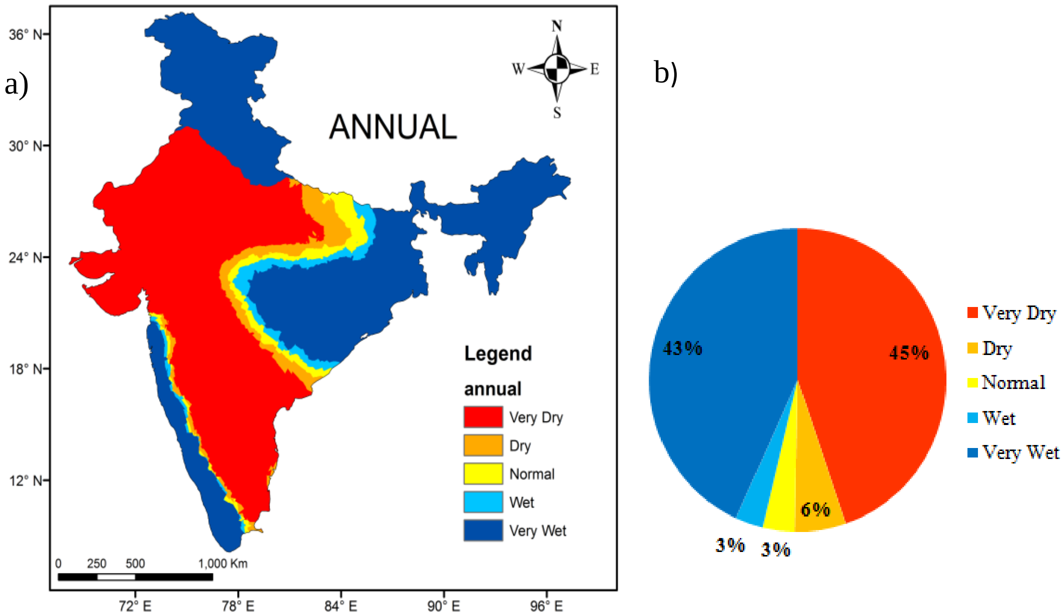


Fig. 14. (a) Spatial distribution of annual rainfall (b) Area under different themes for annual rainfall

The results are in agreement with the reports of Singh, 2011, Singh, 2013 and Singh *et al*. (2009). As per the study with the changing global climatic scenario, the different moisture regions of the country show large variations from one year to another. The overall climatic condition of the country shows drier tendency in the recent years or decades (Singh, 2011; Singh, 2013; Singh *et al*., 2009). It is important to note that most of the agricultural and other water-dependent human activities are spread in dry areas of Indo-Gangetic plains, northwest India and peninsula (excluding the West Coast). During recent decades (1979–2011), the monsoon rainfall over India was less by 4.51% compared to the period 1949–1978 (Ranade *et al*., 2008; Sontakke *et al*., 2008).

4.1.3 Causes of rainfall variability

Analysis of various meteorological parameters across the globe will help in understanding the monsoon system that modulates the changing rainfall pattern. Though many factors are responsible for Indian summer monsoon rainfall, it might largely be modulated by the large-scale atmospheric circulation. Global circulation in terms of precipitation is an important element for the functionality of the earth's system. It helps to regulate the temperature of the earth by transporting heat and moisture from tropics to higher latitudes. Any disturbances in this system will affect the circulation behavior and related processes.

4.1.3.1 Mean sea level pressure (MSLP)

The spatio-temporal variability of the mean sea level pressure (MSLP) is also very important to understand the complexity of the climate system. Anomaly is the best method to represent the change of any parameter from the normal; hence the monthly and seasonal MSLP anomalies were examined. During the current warming scenario, the MSLP was showing a positive trend over the Northern Hemisphere except the extreme North Polar Region. Mean sea level pressure has increased by 1 to 7 hPa over continental Asia, especially Northern parts of India, Tibetan plateau, China, and Mangolia. The mean sea level pressure was decreasing over the South Temperate Regions by 1 to 3 hPa; over South Polar Region by 4 to 7 hPa (Fig. 15).

The composite analysis for the good and bad monsoon years were conducted from 10 good and 10 bad monsoon years based on the highest and lowest all India summer monsoon rainfall amounts. The good monsoon years were 1955, 1956, 1961, 1964, 1971, 1975, 1978, 1983, 1988, and 1994 while the bad monsoon years were 1951, 1965, 1966, 1972, 1979, 1982, 1986, 1987, 2002, and 2004.The composite anomaly spatial plots of MSLP for good and bad monsoon years are illustrated (Fig. 16 and Fig. 17). During the good monsoon years, the mean sea level pressure has been lowered by 1 to 5 hPa over continental Asia. An increase in mean sea level pressure of 1 to 4 hPa over south of 55 °S was observed during the post climatic shift (Fig. 16).The composite anomaly plot of bad monsoon years showed a higher mean sea level pressure of about 1to 3 hPa over continental Asia during the post climatic shift. Though different in magnitude, the similar results were obtained for other monsoon months and seasons. The bad monsoon years composite anomaly plot and the global changes in mean sea level pressure pattern during the summer monsoon (2^{nd} half - 1^{st} half) were similar. The global mean sea level pressure field during post climatic shift was similar to that of bad monsoon years.

For getting good monsoon rainfall, lower mean sea level pressure over the northern hemispheric land mass is required, especially over continental Asia, while higher mean sea level pressure over the Southern Hemisphere and oceanic mass. Due to climate change, it was observed that normal conditions were reversed after climate shift. Hence, it led to the reversal of the normal pressure gradient pattern. The increase in mean sea level pressure over continental Asia largely modulated the weakening of the convective activities over the region and in turn the declining summer monsoon rainfall trend was observed during the last few decades.

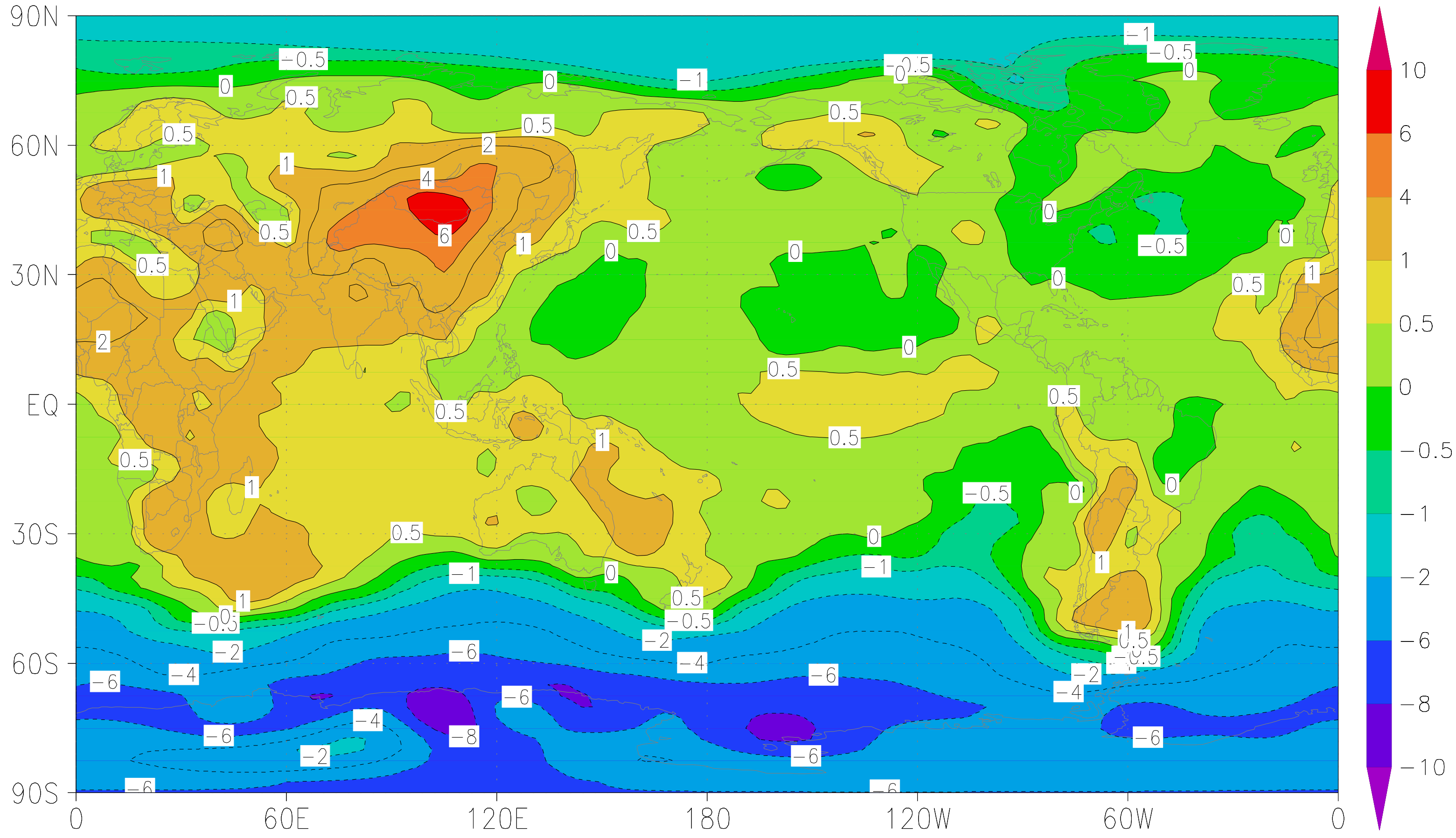


Fig. 15. Global pattern change in MSLP during the summer monsoon (2nd half (1979-2014) - 1st half (1949-1978)).

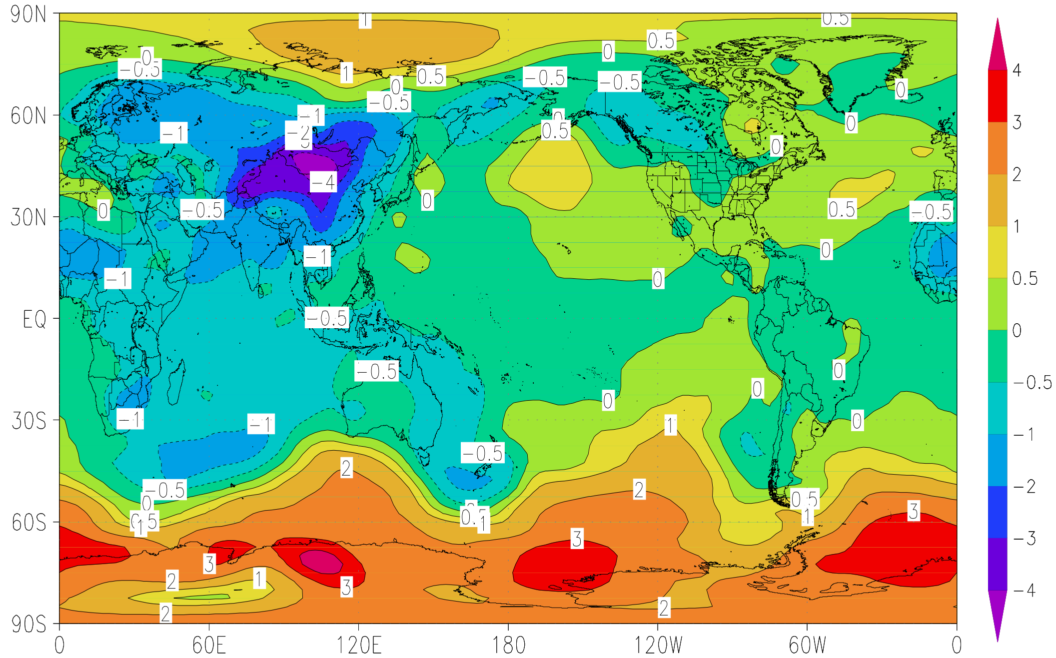


Fig. 16. Composite anomaly of mean sea level pressure for ten good monsoon

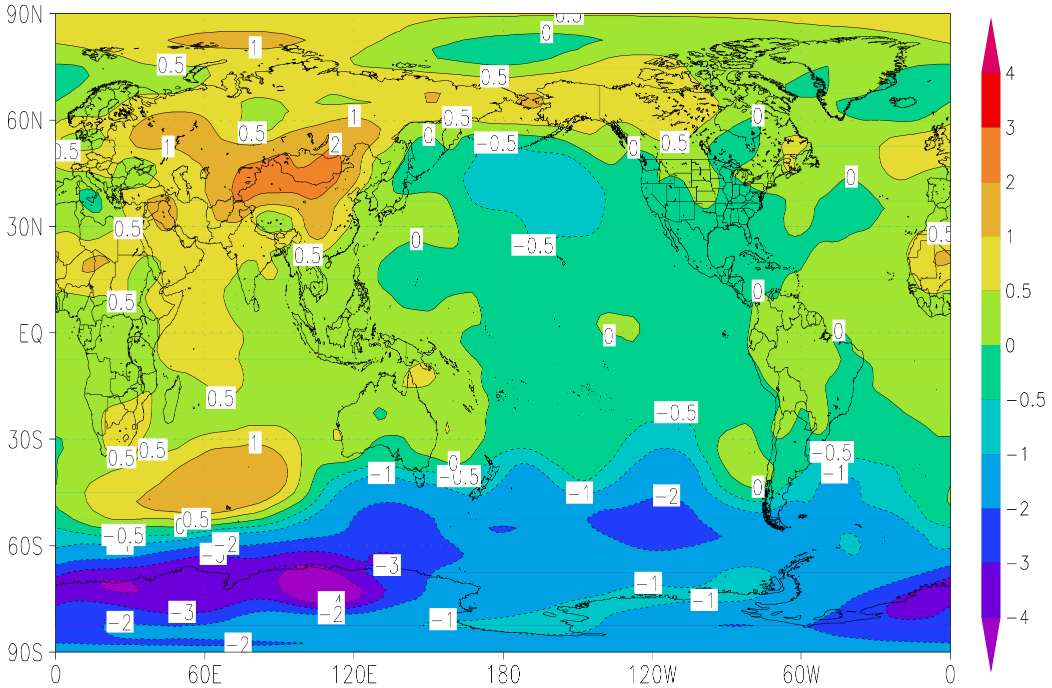


Fig. 17. Composite anomaly of mean sea level pressure for ten bad monsoon

4.1.3.2 Tropospheric temperature

Understanding the science of climate change and impact of rising trend in global tropospheric temperature (TT) on environment, hydrometeorological services and society are important problems of contemporary research. The impact of the global upper tropospheric temperature (500-200 hPa) and lower tropospheric temperature (925-500 hPa) on the Asia-India monsoon system and its associated rainfall over India have also been examined. Similar to the analysis carried out for the mean sea level pressure, analysis were carried out for the upper as well as the lower tropospheric temperatures. The warming of tropospheric temperature for all the climatic zones were noticed but the warming was uneven. The change in global tropospheric temperature patterns during the summer monsoon season from the 2nd half (1979-2014) to the 1st half (1949-1978) is presented in Fig. 18. The spatial plots showed a fall in 1°C in tropospheric temperature over continental Asia. An increase in tropospheric temperature more than 1°C was observed over oceanic south temperate regions during 2nd half. The tropospheric temperature over Mangolia, some parts of China and adjoining parts of Russia decreased (0.5 to 2.0 ^{o}C) where as at the south of 30°S it increased (0.6 to 2.0 ^{o}C).

Increase in the global tropospheric temperature was 0.59 °C while it was 0.87 and 0.32 °C over the southern and northern hemisphere respectively. The tropospheric temperature all over the globe was found to increase. The tropospheric temperature was high (0.87 °C) over the southern hemisphere particularly at the temperate zone. A similar pattern was observed for the upper tropospheric temperature as well as the lower tropospheric temperature (Fig. 19 and 20). The tropospheric temperatures over continental Asia were warmer during the pre-climate shift while cooler during the post-climate shift period.

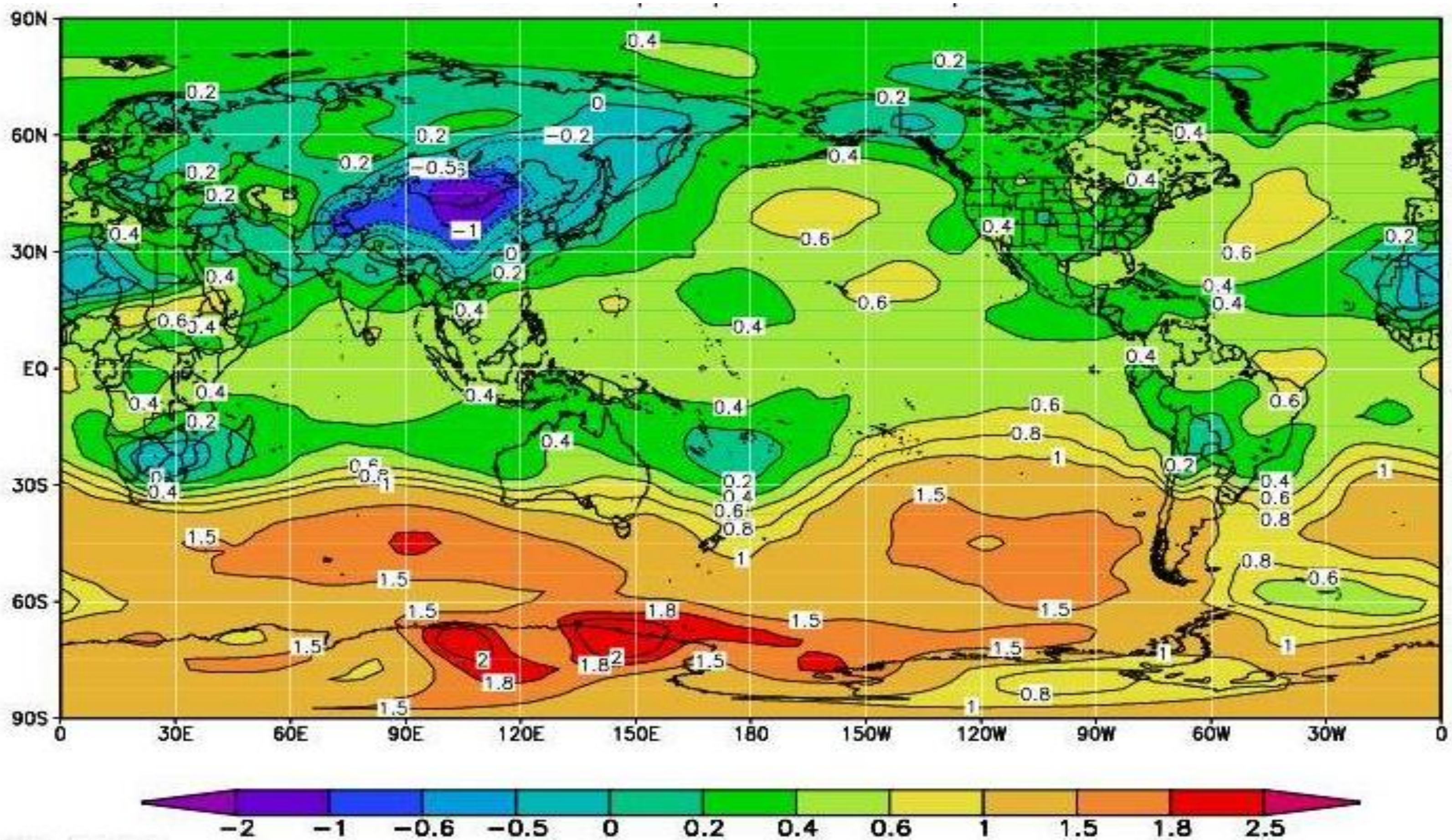


Fig. 18.Global change in tropospheric (1000-200 hPa) temperature pattern during summer monsoon(2^{nd} half (1979-2014) - 1^{st} half (1949-1978))

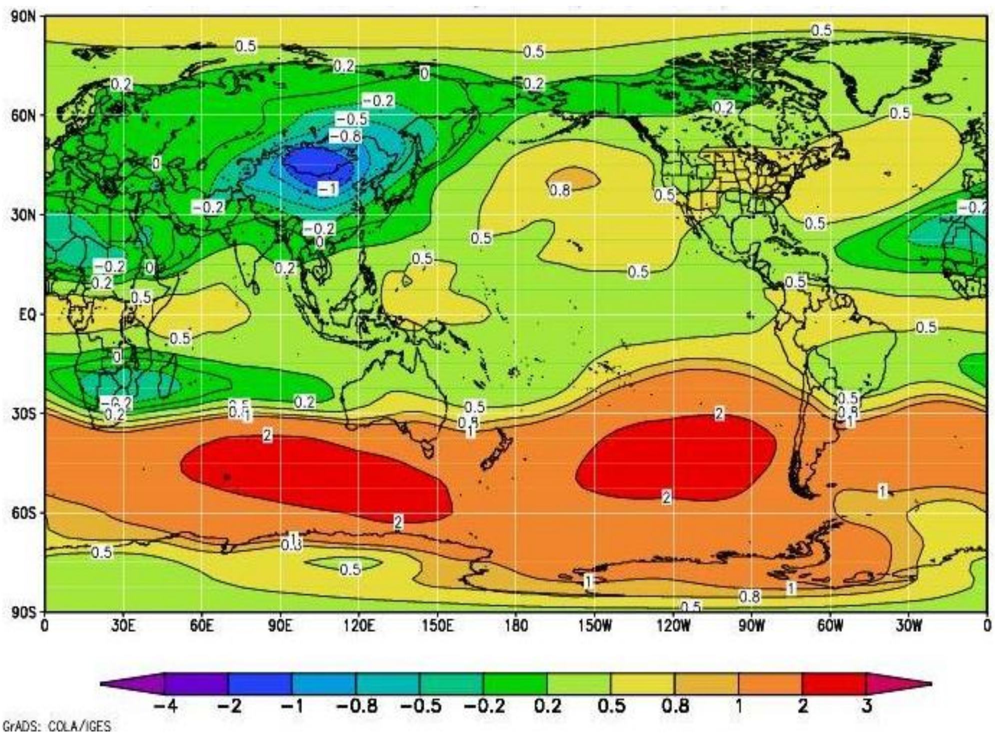


Fig. 19. Global change in upper tropospheric (500-200 hPa) temperature pattern during the summer monsoon

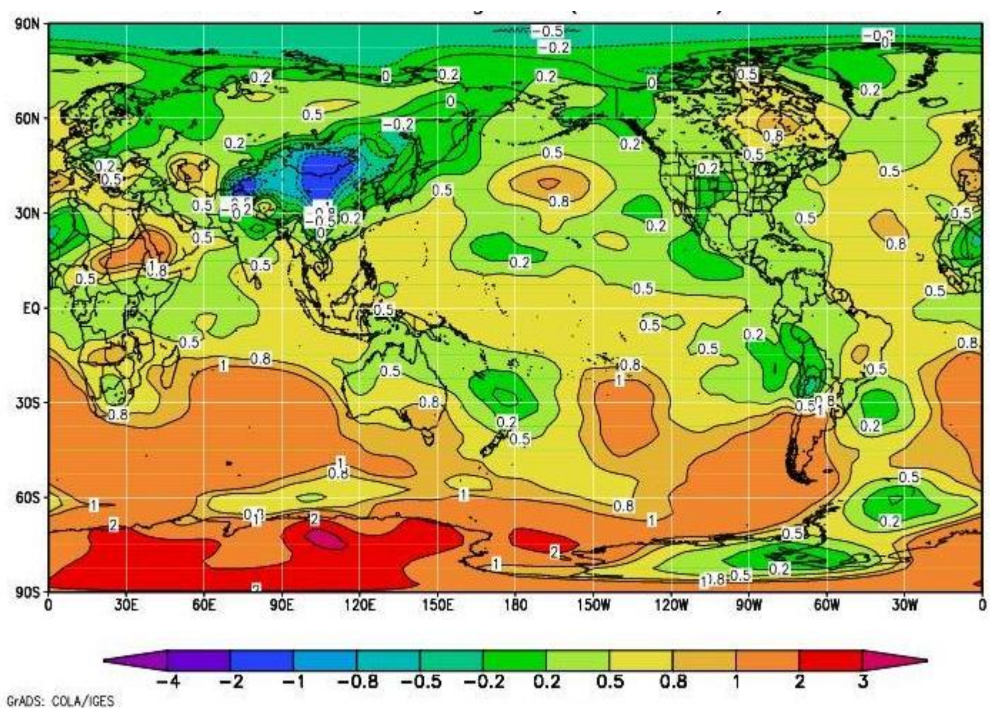


Fig. 20. Global change in lower tropospheric (925-500 hPa) temperature pattern during the summer monsoon

The composite anomaly spatial plots of the tropospheric temperature for good monsoon years and bad monsoon years are presented in Fig. 21 and 22 respectively. During the good monsoon years, the tropospheric temperature (925-200 hPa)was increased by 0.4 – 1.0 °C over the continental Asia likewise extreme northern parts of India, Tibetan plateau, China, and Mangolia however observed a decreasing temperature (0.4°C – 1°C) over the bad monsoon year composite anomaly spatial plot (Fig. 22). The bad monsoon years composite anomaly spatial plots of the Tropospheric temperature show a decreased tropospheric temperature of about 0.6°C – 1.0 °C over the continental Asia during the post climatic shift(Fig. 22).On the Southern Hemisphere south of 35°S noticed a positive anomaly during the bad monsoon years. Though different in magnitude, the similar results were obtained for other monsoon months and seasons. The pattern of the bad monsoon year composite anomaly spatial plot and the global pattern change in tropospheric temperature during the summer monsoon (2^{nd} half (1979-2014) - 1^{st} half (1949-1978)) were similar. This implies that the post climatic shift global tropospheric temperature (925-200 hPa) field was similar to that of the pattern exhibited during the bad monsoon year composite anomaly spatial plot. The global tropospheric temperature (925-200 hPa) changes are not confined to the summer monsoon but noticed during each of the 12 calendar months.

The warming of the troposphere was relatively high (0.87 °C) over the Southern Hemisphere when compared to that of the Northern Hemisphere due to larger water bodies. Since, the heat capacity of ocean mass is much higher than compared to that of land regions. The reduction in the thermal contrast from the continental Asia to southern hemisphere temperate zone modulates the weaker monsoon circulation and in turns the decreased rainfall activities over India.

The results are in agreement with the findings of Sooraj *et al*., 2014. As per the assessments from the CMIP5 models, the warming scenario of the globe and the weakening of the Asian summer monsoon circulation reported in the study (Sooraj *et al*., 2014).

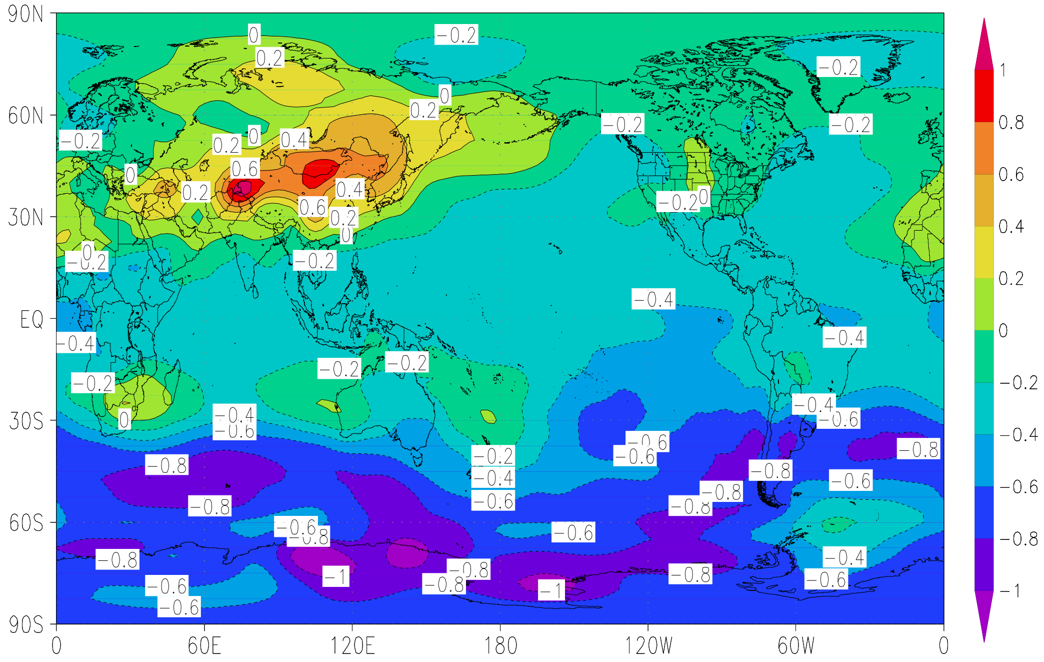


Fig. 21. Composite anomaly of tropospheric (925-200 hPa) temperature for ten good monsoon years

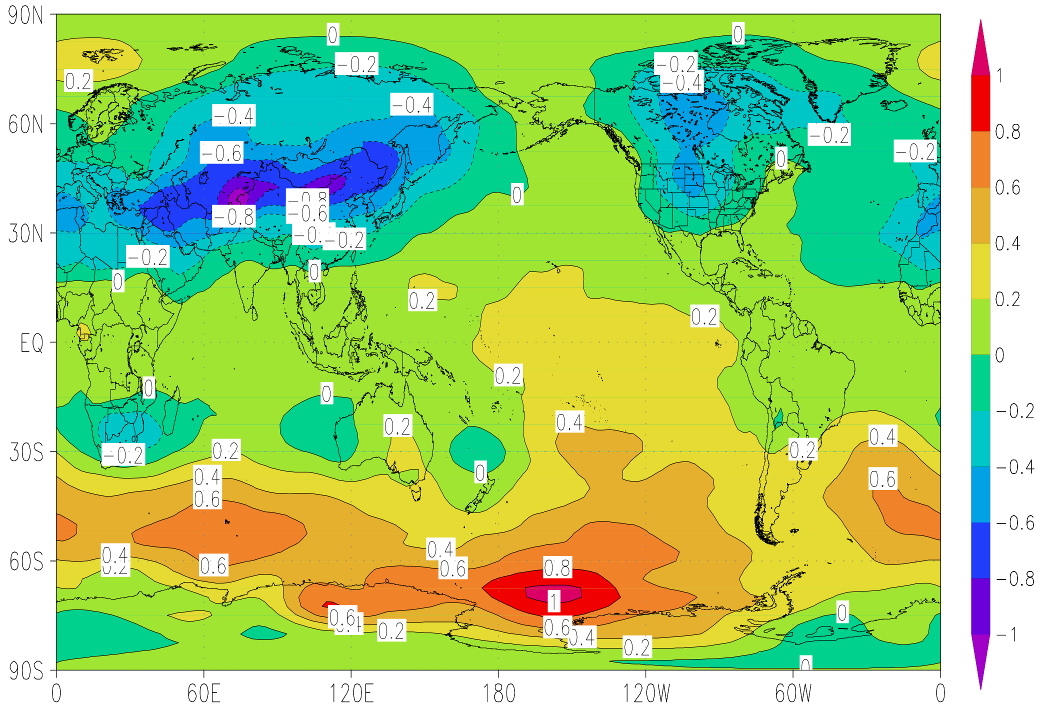


Fig. 22. Composite anomaly of tropospheric (925-200 hPa) temperature for ten bad monsoon years

Meridional temperature gradient plays a role in Asian summer monsoon and this is in agreement with the present study.

Though different in magnitude, the streamline-isotach of the bad monsoon year composite anomaly spatial plot and the global pattern change in the lower troposphere (Fig.23; Fig. 24) during the summer monsoon (2^{nd} half (1979-2014) - 1^{st} half (1949-1978)) were similar. The opposite direction appeared in the streamline-isotach indicated the weakening of the resultant wind. Similar pattern was also observed in the upper level.

The difference in temperature and pressure are key driving forces for wind. The thermal gradient caused by the lower tropospheric warming and corresponding cooling over the upper troposphere largely regulate the atmospheric general circulation patterns. The weakening of the pressure gradient and thermal contrast over north-south hemisphere and land-ocean mass resulted in the weakening of the strength of the resultant wind.

In the past, relationship between monsoon rainfall and regional atmospheric circulation features was studied by composite data of five good and bad monsoon years over India (Sikka, 1980). The results showed a similar trend in the present study. Similar studies (Bansod *et al*., 2012) were carried out on changes in four selected regional circulation parameters viz., zonal wind at 200 hPa level over Tibetan Anticyclone region (TA_{U200}), zonal wind at 100 hPa over peninsular India i.e. Tropical Easterly Jet (TEJ_{U100}), meridional wind (Somali Jet) at 850 hPa over Somali Coast (SJ_{V850}) and meridional wind at 850hPa over Arabian Sea (AS_{V850}). These parameters were studied to analyze their influence on ISMR. The results showed that AS_{V850} and TEJ_{U100} showed decreasing tendency which in turn led to the weakening of the moisture transport mechanism over the Indian sub-continent during the monsoon season. From the present study, it was found that resultant winds were showing decreasing tendency in magnitude. The results are in agreement with the findings of Bansod *et al*. (2012).

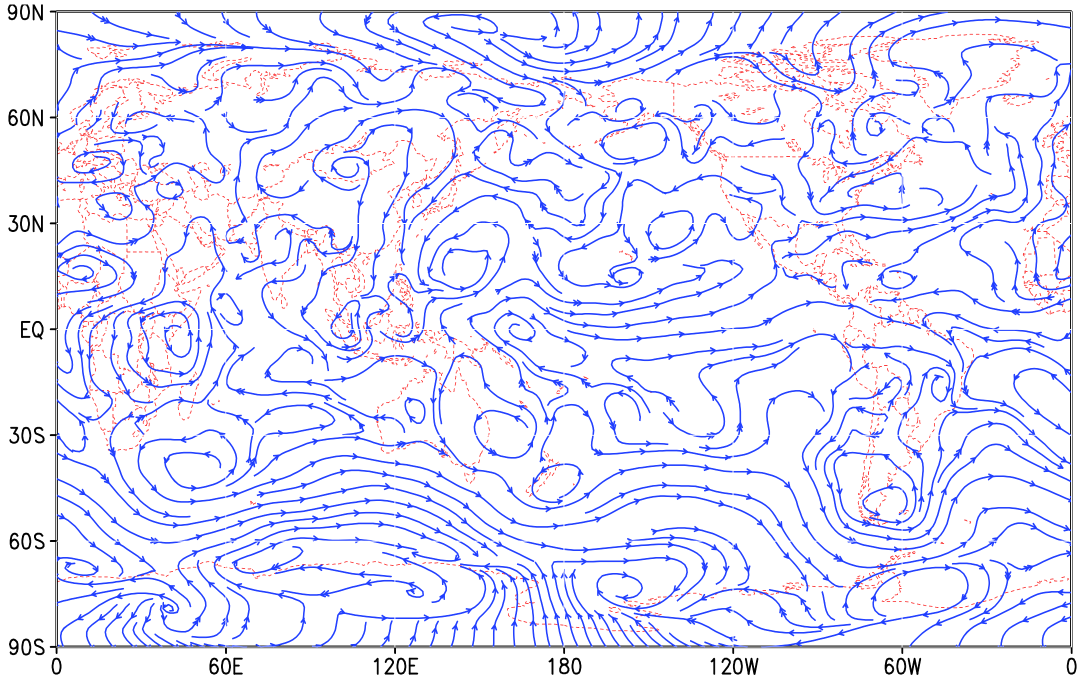


Fig. 23. Global pattern change in lower tropospheric (925-500 hPa) resultant wind during the summer monsoon

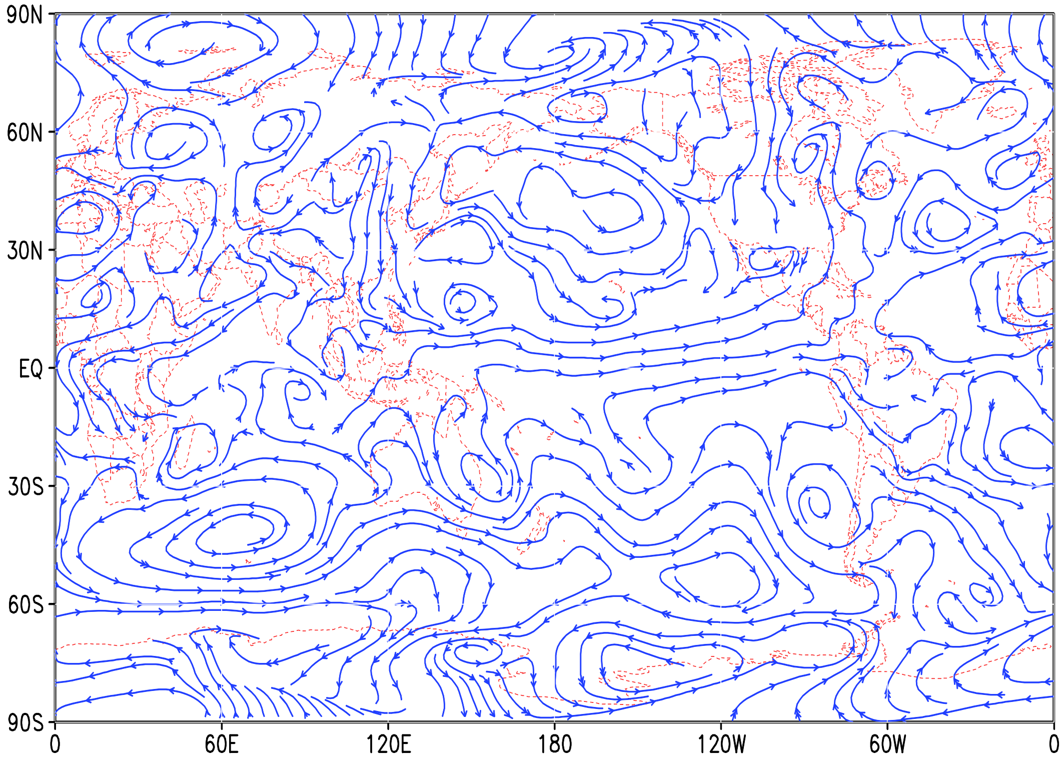


Fig. 24. Composite anomaly of lower tropospheric resultant wind (925-500 hPa) bad monsoon

4.1.3.3 Geopotential height (GPH)

Geopotential height is a vertical coordinate referenced to earth's mean sea level with an assumption that earth's surface was a perfect and flat sphere. It is an adjustment to geometric height (elevation above mean sea level) using the variation of gravity with latitude and elevation and thus it can be considered a "gravity-adjusted height". It approximates the actual height of a pressure surface above mean sea-level. Therefore, a geopotential height observation represented the height of the pressure surface on which the observation was taken. The thickness of the geopotential height in the upper layer and lower layer were also computed.

The global pattern of geopotential height change showed that the troposphere was shrunk by 60 m over the continental Asia and inflated by 90 m over the oceanic south temperate region. Both temperature and pressure were inversely proportional to each other. Since cold air is denser than warm air, it caused pressure surfaces to be lower in colder air masses, while less dense, warmer air allowed the pressure surfaces to be higher. Closely spaced contours indicated stronger wind. As temperature increases, the air above it expanded. Hence the tropospheric thickness was increased over the regions showing a rise in temperature. Areas of reduced temperatures are regions of high pressure. This was evident when we are compared the graphs of change in MSLP and TT. The regions showing positive trends in TT were experiencing reduced MSLP. Not only the temperature gradient but also the pressure gradient across the Indian landmass played a major role in controlling the climate system in and around the Indian subcontinent.

The results were similar with that of Harzallah and Sadourny (1997) and Dash *et al*. (2004). Harzallah and Sadourny (1997) found out an important precursor for monsoon which is a negative centre of geopotential height over Siberia appearing as early as late summer.

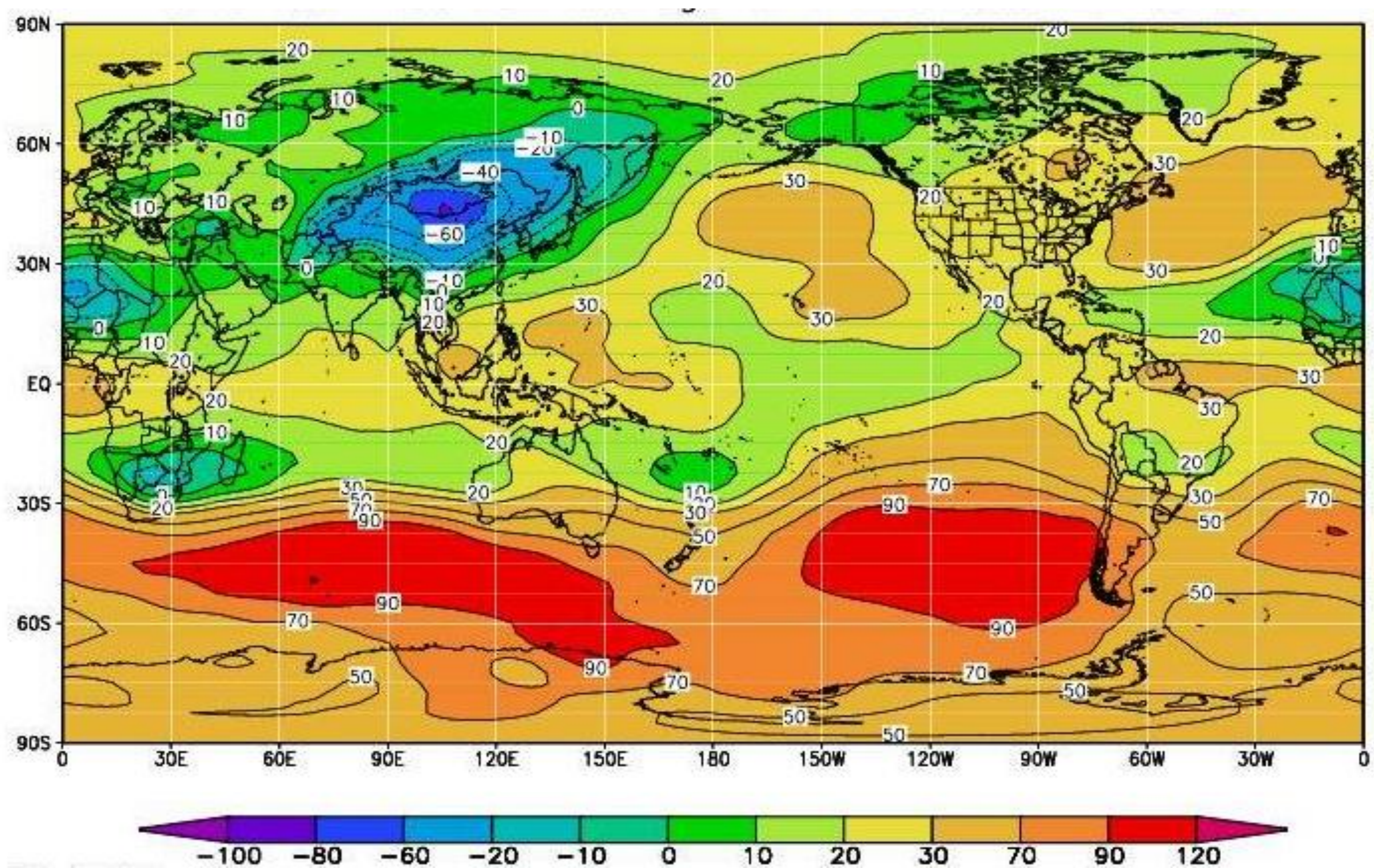


Fig. 25. Global pattern change in tropospheric (925-200 hPa) geopotential height thickness during the summer monsoon (2^{nd} half (1979-2014) - 1^{st} half (1949-1978))

4.1.3.4 Sea surface temperature (SST)

The sea surface temperature (SST) is a measure of the energy due to the motion of molecules at the top layer of the ocean. The changing oceanic conditions are the manifest through sea surface temperature (SST) and thus the SST can influence atmospheric circulation through a variety of processes, largely by changing enthalpy fluxes across the surface. The SST anomalies play an important role in atmospheric variability and predictability.

Fig. 26 shows the global pattern of the summer monsoon season sea surface temperature change from the 2nd half to the 1st half. This spatial plot showed that the global sea surface temperature during the post climatic shift was warmer except some isolated cooling over the Northern Central Pacific, where a decrease of 0.3 ^{o}Cwas noticed. The SST showed an increase of 0.4 to 0.6 ^{o}C over the Equatorial, Southern Indian Ocean and Eastern and Equatorial Pacific. These are regions where the Indian Ocean Dipole and El-Nino are exhibited respectively. The composite anomaly spatial plots of the sea surface temperature for 10 good monsoon years and 10 bad monsoon years had been prepared. During the good monsoon years, the entire oceanic region was observed with a cooling sea surface except some isolated pockets over the Central North Pacific Ocean (0.2 °C – 0.8 °C) , Southern Ocean (0.2 ^{o}C), and the South Pacific Ocean(0.2 ^{o}C). The SST has been cooled down by 0.8 °C – 1.0 °C over the Peru coast and this sea surface cooling region was extended up to the equatorial central Pacific Ocean (Fig. 27). The spatial plot of the SST composite anomaly for good monsoon years is almost similar to La Nina condition. The opposite spatial pattern is observed during the bad monsoon years, which was similar to El-Nino conditions (Fig. 28) and in this case, the Eastern Pacific, especially over Peru coast, Equatorial Pacific, and Western Indian Ocean had been exhibiting warming condition. The sea surface temperature over the Equatorial Pacific was high (0.6 ^{o}C), while it was low (0.2 ^{o}C) over the Northern Central Pacific.

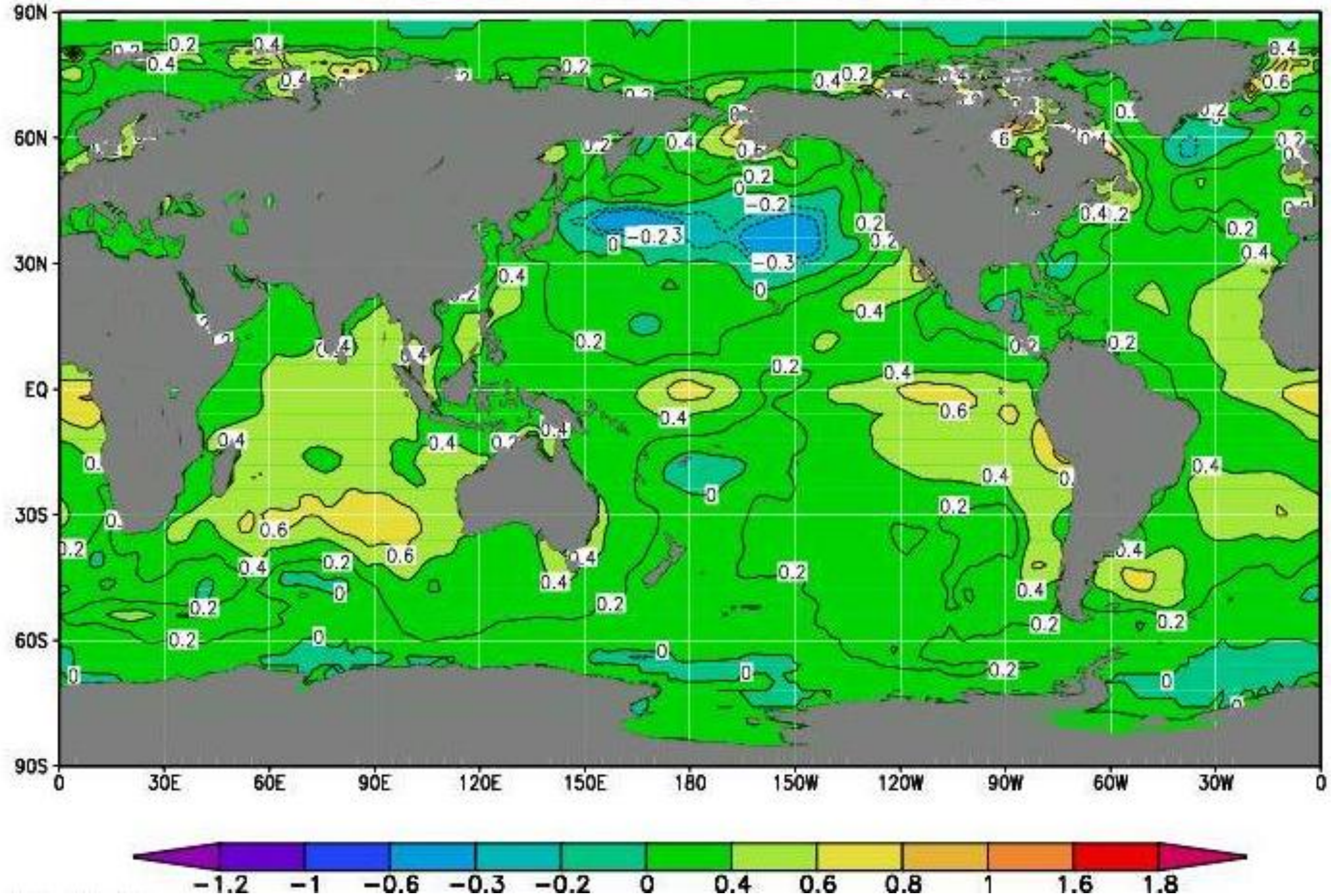


Fig. 26. Global pattern change in Sea surface temperature during the summer monsoon (2nd half (1979-2014) - 1st half (1949-1978))

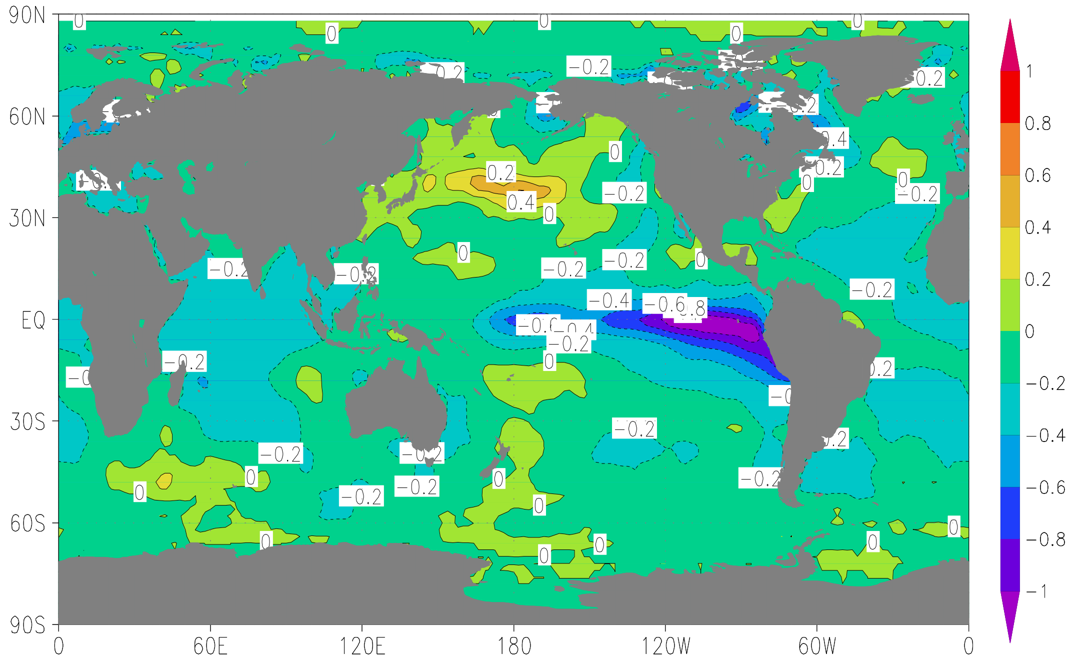


Fig. 27. Composite anomaly of sea surface temperature (SST) for ten good monsoon years

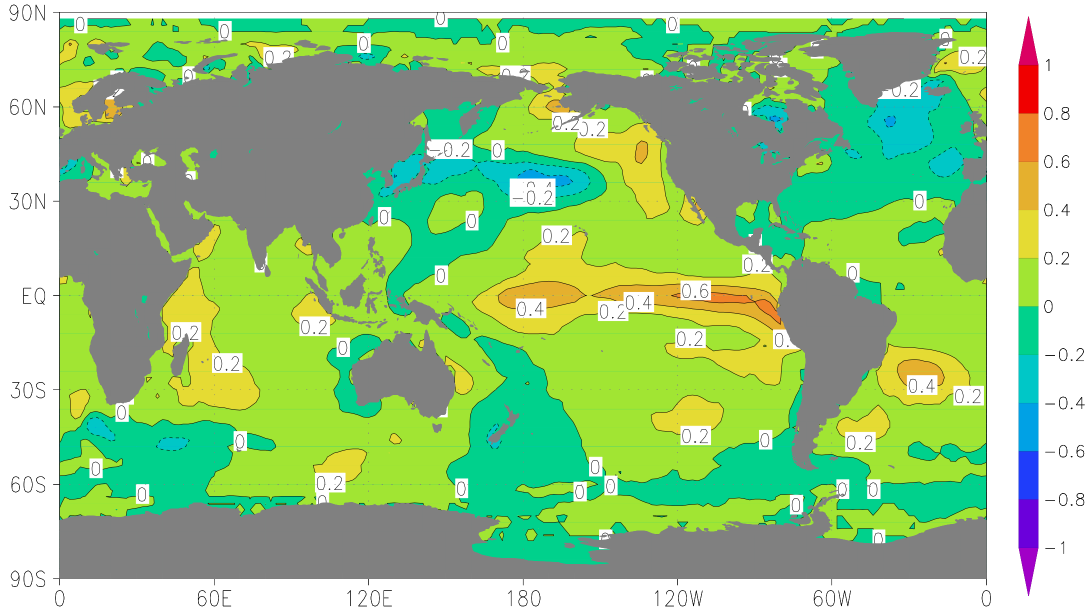


Fig. 28. Composite anomaly of sea surface temperature (SST) for ten bad monsoon years

From the Fig. 28, it was revealed that the Equatorial Pacific was warming more when compared to that of North Central Pacific. It may due to the El-Nino condition which prevailed over the region. Though the magnitude of the change in the sea surface temperature was small, its influence to the atmospheric circulation was enormous, because oceans play an important role in exchange of energy. Change in sea surface temperature may affect the temperature and pressure gradient over the regions. Hence, it may affect the normal circulation pattern.

The relationship of all India summer monsoon rainfall with various teleconnection indices like Southern Oscillation Index (SOI), Nino 4, Nino 3.4, Nino 3 and Arctic Oscillation (AO) was also examined using concordant correlation. The month of June exhibited very highly significant (1 per cent significant) correlation with the Nino 3 and Arctic Oscillation. In July and September months very highly significant correlations with all the indices except Arctic Oscillaion were observed (Table9). Monthly rainfall during August and September were exhibited a correlation at five per cent significance level with the Arctic Oscillation. Seasonal rainfall did not exhibit any significant correlation with the indices. Warming over the Equatorial Pacific showed a negative correlation with the rainfall. This is in agreement with the reports of Buermann *et al*. (2005), which showed a significant positive correlation between Arctic Oscillation and rainfall during the month of June.

Several studies on the impact of El-Nino on Indian summer monsoon rainfall are reported. The findings of the present work are in agreement with the Angell (1981); Rasmusson and Carpenter (1983); Ropelewski and Halpert (1987) and Shukla (1987).

4.1.3.5 Cramer’s t_k test

The monthly 31year Cramer’s t_k test for the surface air temperature and mean sea level pressure are presented below, which shows the cumulative effect of the parameter over the period. From the Table 11, it was observed that the cumulative effect in the changes of surface air temperature was not significant as mean sea level pressure during the month of June. Mean sea level pressure was very highly significant when the central year was considered as 1989. The pattern of mean sea level pressure during July and August was similar to that of June. Surface air temperature was very highly significant when 1969 and 1999 were considered as the central year during July. Similar patterns were observed in August and September also. Cumulative effect of mean sea level pressure was highly significant during September when 1969, 1979, 1989, and 1999 as central years. The annual and monsoon season 31 year cramer's t_k test is given in Table 10.

The mean sea level pressure exhibited a very highly significant change when 1969, 1989, and 1999 were considered as central years during annual and monsoon season. Surface air temperature during monsoon was very highly significant when 1969 and 1999 were considered as central years, but during annual, changes were highly significant when 1979 and 1989 were considered as central years. From both tables, it is observed that there were very highly significant changes for both parameters after climate shift.

Table 9. Concordant correlation between all India monthly rainfall and teleconnection indices during June, July, August, September, and summer monsoon rainfall

	SOI	Nino 4	Nino 3.4	Nino 3	AO
June	0.18	-0.18	-0.24^{*}	-0.31^{**}	0.36^{**}
July	0.32^{**}	-0.34^{**}	-0.37^{**}	-0.38^{**}	0.07
August	0.19	-0.18	-0.20^{*}	-0.20^{*}	0.20^{*}
September	0.40^{**}	-0.54^{**}	-0.57^{**}	-0.49^{**}	0.25^{*}
JJAS	0.39	-0.45	-0.51	-0.49	0.33

(** significant 1 % level and * significant 5 % level)

Table 10. Annual and monsoon 31 year Cramer's t_k test

Monsoon		
Central year	SAT	MSLP
1969	-3.09*	-4.93*
1979	-0.05	1.80
1989	-0.18	7.02*
1999	2.94*	6.10*
Annual		
Central year	SAT	MSLP
1969	-1.23	-4.81*
1979	-4.16*	2.00
1989	-6.15*	7.32*
1999	-0.76	5.43*

(SAT: surface air temperature, MSLP: mean sea level pressure * significant at 1 % level)

Table 11. Monthly 31 year Cramer's t_k test statistics

JUNE		
Central year	SAT	MSLP
1969	-0.79	-3.65*
1979	1.22	0.17
1989	-0.09	4.20*
1999	0.48	4.15*
JULY		
Central year	SAT	MSLP
1969	-2.27*	-3.96*
1979	-0.15	1.90
1989	-0.33	6.26*
1999	2.44*	4.59*
AUGUST		
Central year	SAT	MSLP
1969	-3.61*	-5.45*
1979	-1.32	1.19
1989	0.46	4.68*
1999	4.29*	6.88*
SEPTEMBER		
Central year	SAT	MSLP
1969	-4.74*	-3.47*
1979	-2.01	2.66*
1989	-0.53	7.18*
1999	3.81*	4.44*

(SAT: surface air temperature, MSLP: mean sea level pressure,* Significant at 1 % level)

4.1.3.5 Precipitable water and cloud cover

Precipitable water is the depth of water in a column of the atmosphere, if all the water in that column were precipitated as rain. In other words, the total precipitable water is that contained in a column of unit cross section extending all of the way from the earth's surface to the "top" of the atmosphere. Thus, this is one of the most important parameters that induced the rainfall. The cloud clusters are also very important phenomenon associated with the weather and climate. Keeping the importance of these parameters in the study of rainfall variability, the long term fluctuation characteristics of these parameters over and across India for different months and seasons were carried out. The fluctuation characteristics and its changes had also been tested using the 31-yr Cramer's t_k test statistics centered to all possible years in succession. The details of the analysis based on summer monsoon season, monsoon months, and annual scale are discussed below.

The change in precipitable water from 1949 to 2014 is represented in Table 12. It is observed that except North East India (NEI) all other zones experienced decrease in precipitable water over the period from 1949 to 2014. NEI showed an increase in precipitable water (0.36 kg m^{-2}) during post climatic shift. All India annual precipitable water was decreased by 0.37 kg m^{-2} during post climatic shift. West Coast, West Coast (S), Central Peninsular India showed a decrease in precipitable water by 1.38, 1.33, and 1.16 kg m^{-2} respectively. A slight decrease was observed in annual precipitable water over East Coast (S), East Coast (N), Ganga Plains, North Central India, North West India, and South Peninsular India by 0.36, 0.46, 0.42, 0.06, 0.18, and 0.81 kg m^{-2} respectively. All India monsoon precipitable water had decreased by an amount of 0.37 kg m^{-2} over the period. Maximum decrease in precipitable water was observed over West Coast (S), South Peninsular India, West Coast, East Coast (S), and Central Peninsular India by 1.77, 1.74, 1.71, 1.42, and 1.24 kg m^{-2} respectively. All India precipitable water has increased by a value of 0.16 kg m^{-2} in June. During June, maximum decrease was observed over Ganga Plains, East Coast (S), West Coast

(S), and West Coast respectively by 1.73, 1.21, 1.19, and 1.11 kg m^{-2} respectively. A slight increase was observed over East Coast North, North Central India, North East India, North West India, and South Peninsular India by 0.52, 0.62, 0.53, 0.41, and 0.51 kg m^{-2} respectively. All India precipitable water during July was decreased by 0.46 kg m^{-2}. During July decrease in precipitable water was observed over West Coast (S), West Coast, East Coast (S), Central Peninsular India, East Coast (N), Ganga Plains, and North Central India by 2.15, 2.07, 1.73, 1.58, 0.88, 0.85, and 0.67 kg m^{-2} respectively. All India precipitable water during August had decreased by an amount of 0.28 kg m^{-2}. All other zones except South Peninsular India showed a decrease in precipitable water. South Peninsular India showed an increase of 0.27 kg m^{-2}. Maximum decrease was observed over West Coast South, West Coast, and East Coast South by 1.49, 1.42, and 1.17 kg m^{-2}respectively. All India precipitable water had decreased by 0.9 kg m^{-2} in September. All other zones except Ganga Plains (0.12 kg m^{-2}) and North East India (0.36 kg m^{-2}) showed a decrease in precipitable water during September. Maximum decrease was observed over West Coast (S), West Coast, Central Peninsular India, North Central India, East Coast (N), East Coast (S), North West India, and North Mountainous India by 2.25, 2.25, 2.19, 2.19, 1.7, 1.58, 1.39, and 1.07 kg m^{-2} respectively.

The change in cloud cover from 1949 to 2014 is represented in Table 13. It was observed that except East Coast North (0.02 %), North Central India (0.34 %), and North Mountainous India (0.23 %) all other zones had experienced a decrease in cloud cover over the period from 1949 to 2014. All India annual cloud cover was decreased by 1.41 per cent during post climatic shift. South Peninsular India, West Coast (S), West Coast, North East India, and East Coast (S), exhibited a decrease in cloud cover by 2.83, 2.69, 2.44, 2.24, and 1.54 per cent respectively. A slight decrease was observed in annual cloud cover over Ganga plains, North West India, Central Peninsular India by 0.44, 0.65, and 0.26 per cent respectively. All India monsoon cloud cover was decreased by 2.46 per cent over the period.

Table 12. Change in precipitable water over different zones in India

Zones	Precipitable water change over the time period (kg m^{-2})					
	Jun	Jul	Aug	Sep	JJAS	Annual
All India	0.16	-0.46	-0.28	-0.90	-0.37	-0.37
CPI	-0.40	-1.58	-0.78	-2.19	-1.24	-1.16
EC (N)	0.52	-0.88	-0.45	-1.70	-0.63	-0.46
EC (S)	-1.21	-1.73	-1.17	-1.58	-1.42	-0.36
GP	-1.73	-0.85	-0.72	0.12	-0.79	-0.42
NCI	0.62	-0.67	-0.68	-2.19	0.63	-0.06
NEI	0.53	0.06	0.23	0.36	0.29	0.36
NMI	-0.10	-0.31	-0.55	-1.07	-0.51	-0.36
NWI	0.41	0.54	-0.28	-1.39	-0.32	-0.18
SPI	0.51	0.85	0.27	-0.32	-1.74	-0.81
WC (S)	-1.19	-2.15	-1.49	-2.25	-1.77	-1.33
WC	-1.11	-2.07	-1.42	-2.25	-1.71	-1.38

Table 13. Change in cloud cover over different zones of India

Zones	Change in cloud cover (per cent)					
	Jun	Jul	Aug	Sep	JJAS	Annual
All India	-1.45	-2.22	-3.05	-3.12	-2.46	-1.41
CPI	1.12	-2.49	-3.30	-2.27	-1.73	-0.26
EC (N)	2.58	-0.28	-0.26	0.85	-1.92	0.02
EC (S)	1.06	-1.54	-3.36	-2.04	-1.47	-1.54
GP	1.00	-0.56	-0.53	-1.65	-0.11	-0.44
NCI	1.12	-1.88	-1.47	-0.99	-0.80	0.34
NEI	-4.75	-2.42	-3.48	-4.96	-3.90	-2.24
NMI	2.75	1.05	0.82	-2.44	0.55	0.23
NWI	2.28	-1.32	-1.18	-0.31	-0.13	-0.65
SPI	0.00	-1.45	-3.30	-1.46	-1.55	-2.83
WC (S)	0.00	-1.98	-2.89	-2.08	-1.74	-2.69
WC	-0.14	-2.18	-3.33	-1.96	-1.90	-2.44

All other zones except North Mountainous India (0.55 %) showed a decrease in cloud cover during monsoon season. Maximum decrease in cloud cover was observed over North East India, East Coast North, West Coast, West Coast (S), Central Peninsular India, South Peninsular India, and East Coast (S) by 3.9, 1.92, 1.9, 1.74, 1.73, 1.55 and 1.47 per cent respectively. The all India cloud cover had decreased by 1.45 per cent in June. During June, maximum decrease was observed over North East India by 4.75 per cent. An increase was observed over north mountainous India, East Coast North, North West India, North Central India, Ganga plains, and East Coast South by 2.75, 2.58, 2.28, 1.12, 1.0, and 1.06 per cent respectively. All India cloud cover during July decreased by 2.22 per cent. All other zones except North Mountainous India (1.05 %) showed a decrease in cloud cover during July. During July, decrease in cloud cover was observed over Central Peninsular India, North East India, West Coast, West Coast (S), North Central India, East Coast (S), South Peninsular India, North West India, Ganga Plains, and East Coast (N) by 2.49, 2.42, 2.18, 1.98, 1.88, 1.54, 1.51, 1.32, 0.56 and 0.28 per cent respectively. During August, All India cloud cover was decreased by 3.05 per cent. All other zones except North Mountainous India (0.82 per cent) showed a decrease in cloud covers. A decrease was observed over North East India, East Coast (S), West Coast, South Peninsular India, Central Peninsular India, West Coast (S), North Central India, and North West India by 3.48, 3.36, 3.33, 3.30, 3.30, 2.89, 1.47, and 1.18 per cent respectively. All India cloud cover exhibited a decrease of by 3.12 per cent during September. All other zones except East Coast (N) (0.85 %) showed a decrease in cloud cover during September. A decrease was observed over North East India, Central Peninsular India, North Mountainous India, West Coast (S), East Coast (S), West Coast, Ganga plains, South Peninsular India, North Central India, and North West India by 4.96, 2.27, 2.44, 2.08, 2.04, 1.96, 1.65, 1.46, 0.99 and 0.31 per cent respectively.

The total air column summer monsoon season precipitable water over and across India is decreasing except over the north east India. Highly significant (1%

level of significance) decline in the precipitable water is observed over West Coast, South Peninsular India, Central Peninsular India, East Coast (N) and East Coast (S) whereas the North Central India and North Mountainous India are significant at 5 per cent probability level (Fig. 29). The Ganga plains exhibit decadal variability without any trend. These were clearly seen in the 9-point Gaussian low pass filtered values. Though the total cloud cover over India showed a long term decreasing tendency, different zones show different nature of neither increasing nor decreasing tendencies except the highly significant (1 % level of probability) trend found in the North East India (Fig. 30). The 31-year cumulative effect on the change in the pattern for both the parameters was examined by computing the 31-yr Cramer's t_k test statistic (Table 14). Though showing the sharp and significant decreasing trend in the total air column summer monsoon season precipitable water, the cumulative effect was not significant due to the large scale inter-annual variability (Fig. 29). The Cramer's t_k test statistic computed based on the total cloud cover were found to be highly significant (1 per cent level of probability) while considering the centre year as 1979 and 1989.

The trend line of precipitable water in whole India level during the month of June was fluctuating around the mean line with slight positive tendency during the recent two decades. This increasing tendency during the last two decades was due to the increasing moisture contents over the Gangetic Plains (GP), North East India (NEI), and North West India (NWI). Significant decreasing tendencies were observed over the East Coast (S), South Peninsular India, West Coast, and West Coast (S). This was clearly seen through the low pass Gaussian 9-point filtered values. The cloud cover over India is showing a slight increasing tendency since late 1980s. This increasing tendency was due to the significant increase (5% level of significance) over the Gangetic Plains, North Central India and North West India. As far as the whole country is concerned, the low pass 9-point Gaussian filtered values are showing a cyclical fluctuation with maximum values during decade 2000-10 and minimum during 1980-90. The 31-yr Cramer's

t_k test statistic centered considered in different years (1969, 1979, 1989, and 1999) show insignificant for both the parameters during the month of June (Table 15).

Though the long term trend analysis of the total air column precipitable water as well as the total cloud cover for the month of July showed different fluctuating characteristics over different zones of India, the 9-point Gaussian filtered values showed an increasing tendencies during the last three decades. However, the total cloud cover over and across India showed a slight decreasing tendency since 2010. The total air column precipitable water during the month of July over the whole country was showing an insignificant decrease however the total cloud cover showed a significant decreasing trend. The 31-yr Cramer's t_k test statistic (Table 15) shown a highly significant change on both the parameters when considered the year 1989 as centred value due the sharp decreasing tendencies observed after the climate shift.

During the month of the August, the long term fluctuation characteristics of the total air column precipitable water over and across India showed a large inter-annual variation with decreasing tendencies except North East India and North West India. A highly significant decreasing tendency over East Coast (S), West Coast, West Coast (S), and South Peninsular India had also been observed. However, the last decade showed increasing tendencies. The low pass Gaussian 9-point filtered values indicated the reduced moisture content in the atmosphere since early 1980s compared to the long term mean. This was compatible with the characteristics observed on other meteorological parameters. This again seemed to be inter related with the climate shift. Although decreasing tendencies over and across India in the long term fluctuation characteristics of the total cloud cover was observed, non-significant increasing tendencies were also observed since early 1960s. Due to its low inter-annual variability, the cumulative effect in the changes had emerged as significant while computing the 31-yr Cramer's t_k test statistic (Table 15).

Long term fluctuation characteristics of the total air column precipitable water during the month of the September, over and across India showed decreasing tendency except the North East India. Except the North West India, North Mountainous India, and North Central India, highly significant decreasing tendencies had been observed. The North East India showed a very highly significant increasing tendency. However, as observed in the month of August, the last decade showed increasing tendencies. The low pass Gaussian 9-point filtered values indicated the reduced moisture content in the atmosphere since early 1960s compared to the long term mean. This was compatible with the characteristics observed on all India rainfall. The decreasing tendencies expressed over and across India, in the long term fluctuation characteristics of the total cloud cover were non-significant. However, the cumulative effect in the pattern changes had been found as significant while computing the 31-yr Cramer's tk test statistic (Table 15).

The total air column annual precipitable water over and across India had been decreasing except over the North East India (Fig. 31). Highly Significant (1 % level) decline in the precipitable water was observed over West Coast, West Coast (S), Central Peninsular India, and South Peninsular India regions whereas the North Central India and the East Coast (N) were significant at 5 per cent level of significance. The North West India exhibited decadal variability without any trend. These were clearly seen in the 9-point Gaussian low pass filtered values. Though the total cloud cover (Fig. 32) over India showed a long term decreasing tendency, the different zones showed diversity in its increasing and decreasing tendencies. The South Peninsular India, West Coast, and West Coast (S) showed a highly significant (1 % level) decreasing trend since 1969s whereas North Central India, Central Peninsular India and the East Coast (N) showed an insignificant increasing trend. The 31-year cumulative effect on the change in the pattern for both the parameters had been examined by computing the 31-yr Cramer's t_k test statistic (Table 14). These analyses are very highly significant when 1989 is considered as the central year.

Table 14. Computed 31 year Cramer's t_k test statistics for cloud cover, and precipitable water for all India level during monsoon and annual.

Monsoon		
Central year	Cloud cover	Precipitable water
1969	0.6	0.27
1979	-3.25*	-1.36
1989	-5.40*	-1.89
1999	-1.89	-0.63
Annual		
Central year	Cloud cover	Precipitable water
1969	1.38	1.36
1979	0.44	-2.11*
1989	-2.74*	-2.56*
1999	-1.56	-1.07

(* Significant at 1.0 % level)

Table 15. Computed 31 year Cramer's t_k test statistics for cloud cover, and precipiable water for all India level during monsoon months.

JUNE		
Central year	Cloud cover	Precipitable water
1969	-0.08	-0.08
1979	0.41	0.41
1989	0.01	0.01
1999	0.35	0.35
JULY		
Central year	Cloud cover	Precipitable water
1969	-0.03	-0.59
1979	-3.00	-1.64
1989	-2.94*	-2.41*
1999	-0.90	-0.34
AUGUST		
Central year	Cloud cover	Precipitable water
1969	0.30	0.88
1979	-2.79*	-0.43
1989	-4.17*	-1.01
1999	-1.65	-1.01
SEPTEMBER		
Central year	Cloud cover	Precipitable water
1969	1.64	0.66
1979	-2.01	-2.34*
1989	-4.27*	-2.23*
1999	-2.18*	-0.97

(* Significant at 1.0 % level)

Cloud feedback is the coupling between cloudiness and surface air temperature in which a change in surface air temperature could lead to a change in volume of clouds, which could then amplify or diminish the initial temperature perturbation. An increase in surface air temperature could increase evaporation and hence the precipitable water in the atmosphere; this in turn might increase the extent of cloud cover.

Similar studies like role of cloud properties in relation with summer monsoon were conducted (Kiran *et al*., 2009). The study showed statistically significant variations of cloud properties observed over Central and North East India. This is in agreement with the current study.

According to Willium and Houze (1987) the large cloud clusters exhibited meso-scale organization that led to most of the vertical transport of the energy from the planetary boundary layer to the upper troposphere as well as, in turn, the rainfall. This is in confirmation with the present study.

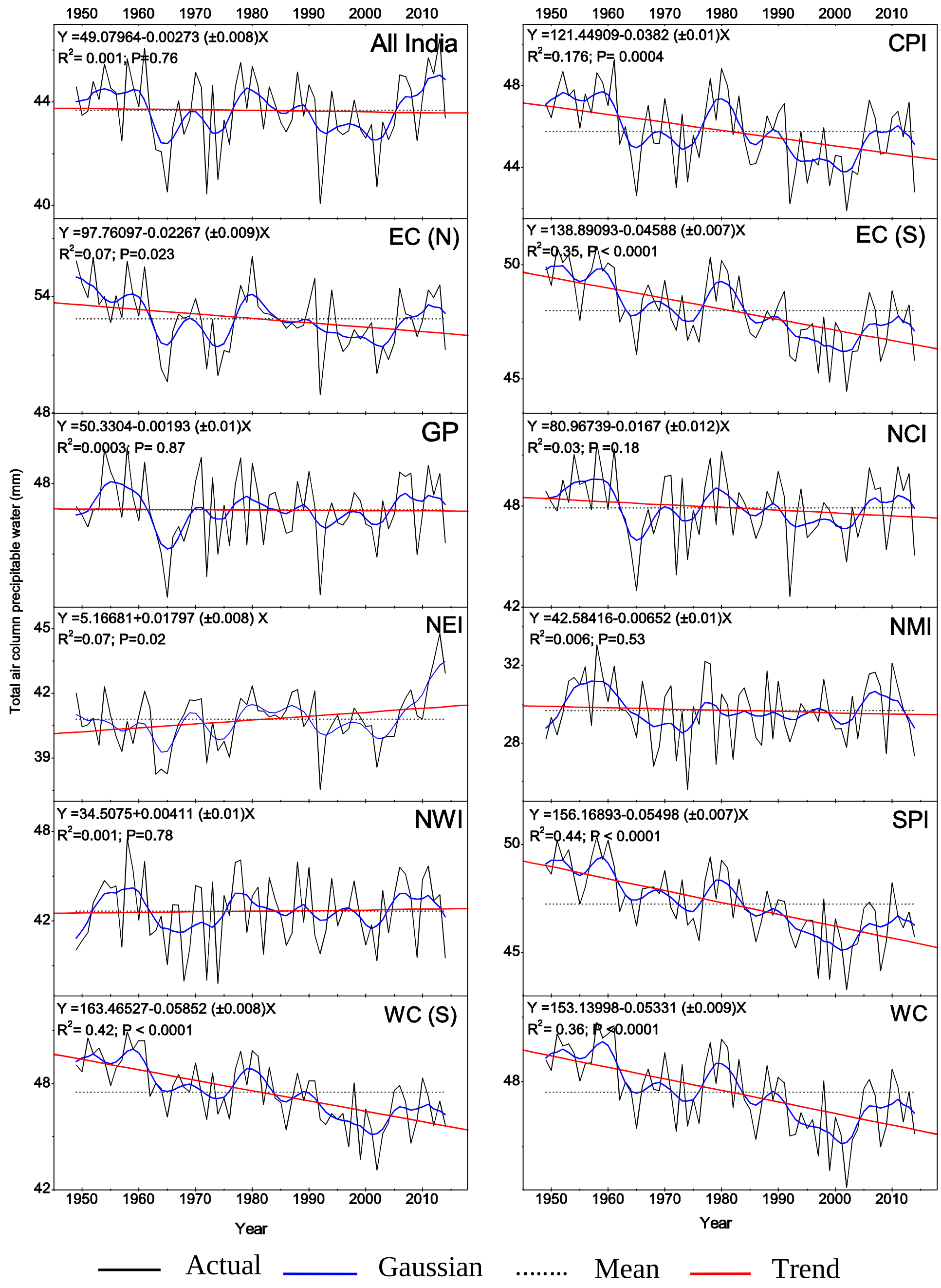


Fig. 29. Precipitable water during monsoon season over 11 zones of the country from 1949 to 2014

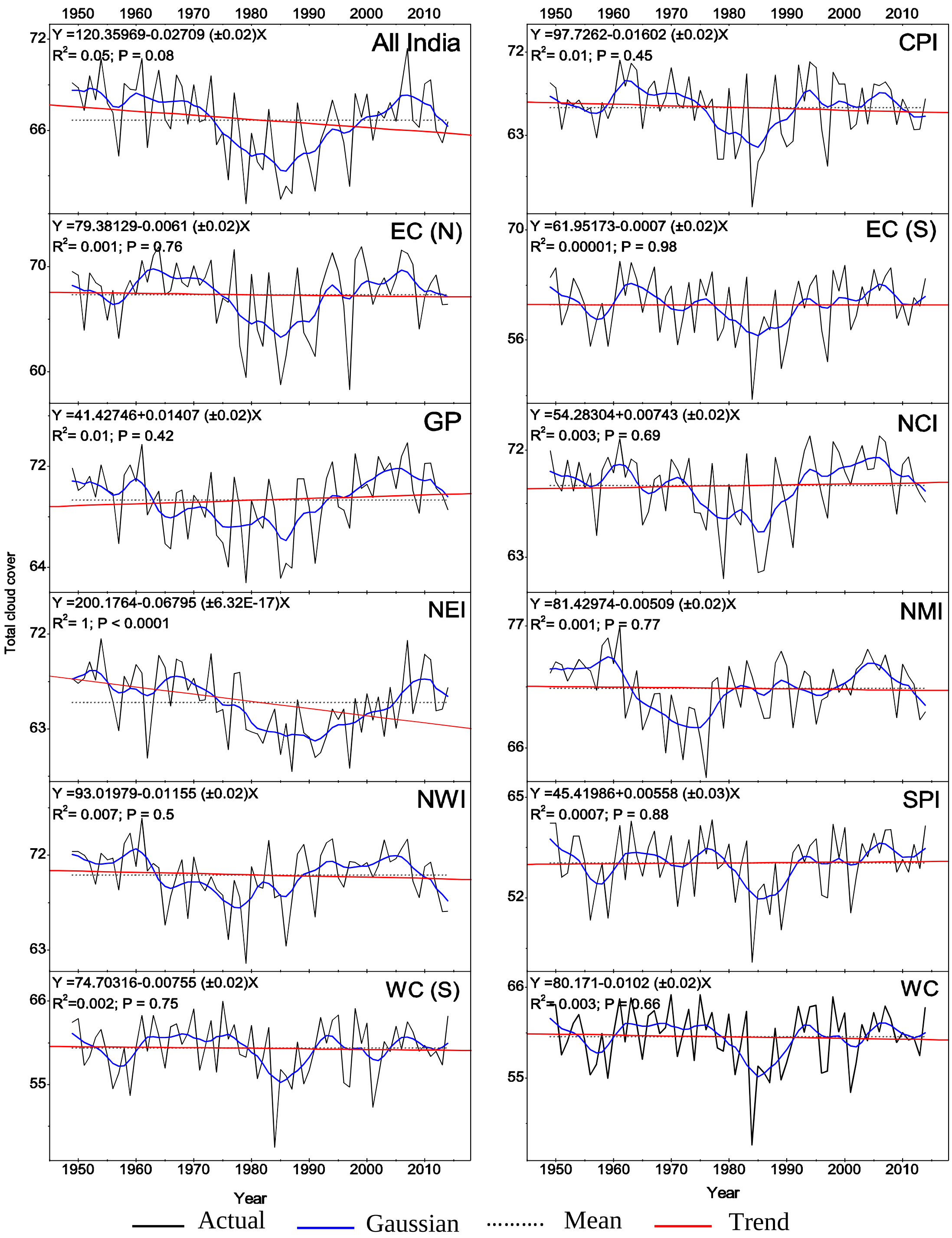


Fig. 30. Cloud cover during monsoon season over 11 zones of the country from 1949 to 2014

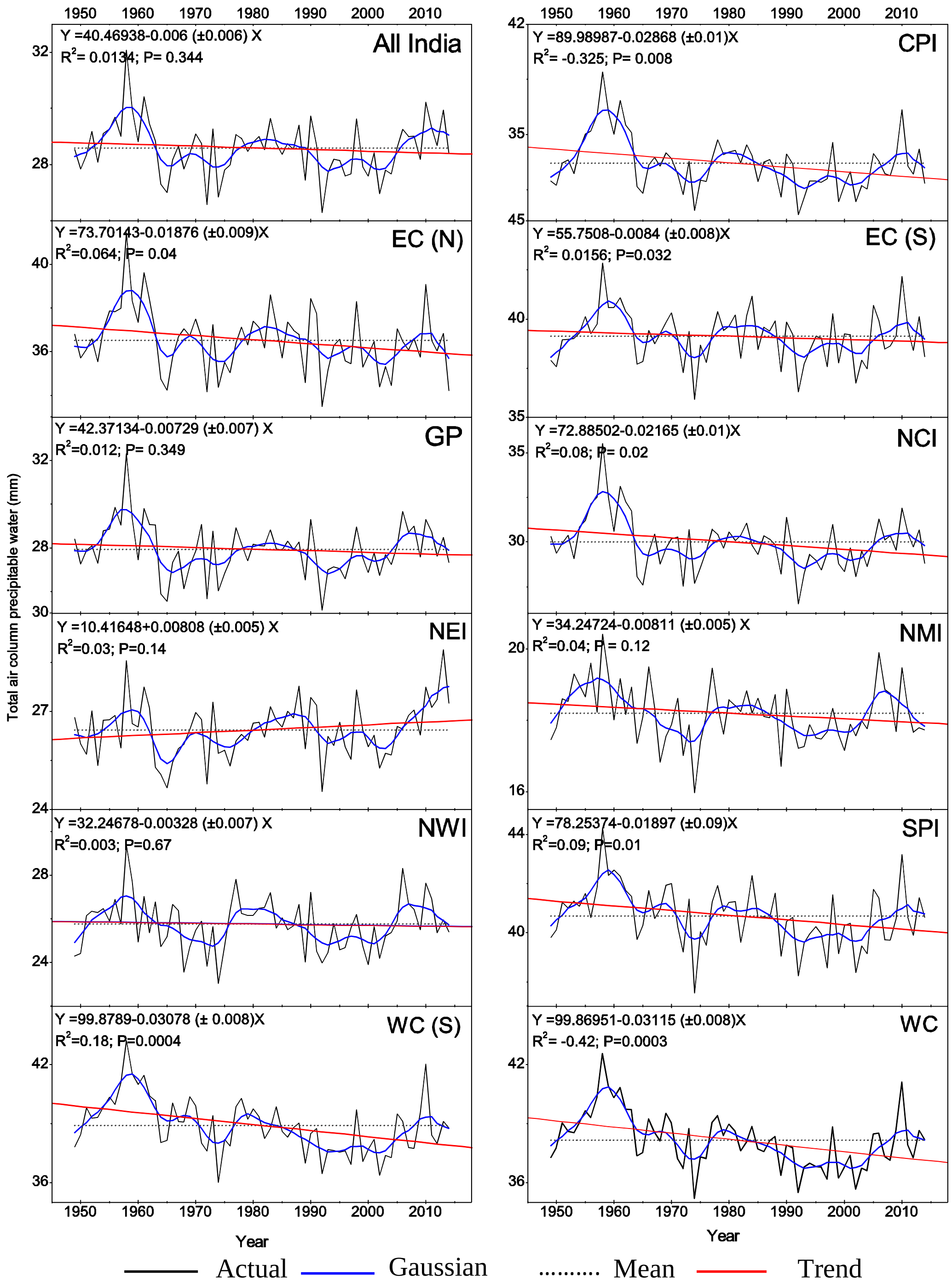


Fig. 31. Annual precipitable water over 11 zones of the country from 1949 to 2014.

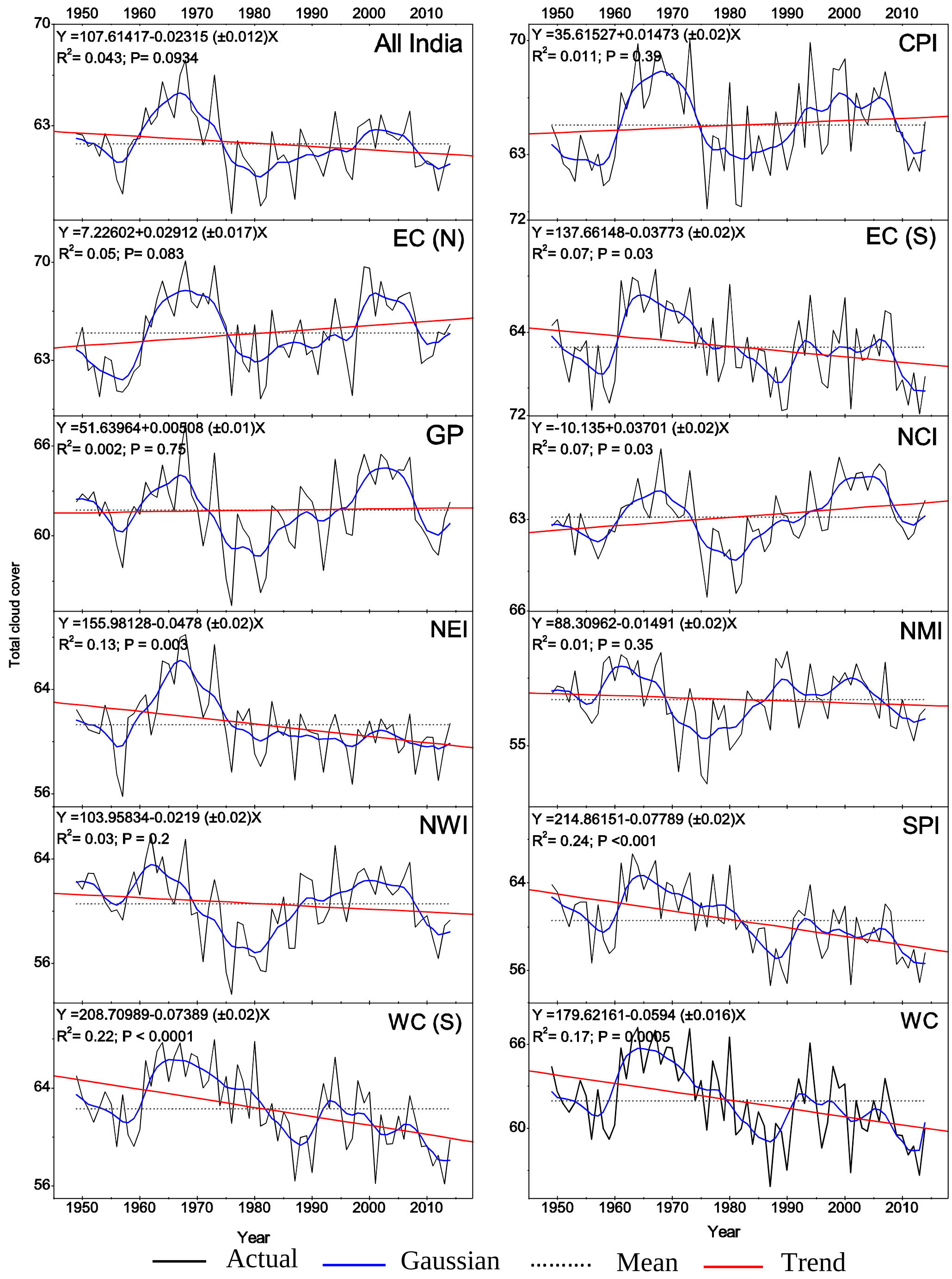


Fig. 32. Annual cloud cover over 11 zones of the country from 1949 to 2014.

4.2 Land use and land cover changes

The land use and land cover data across India documented under the research program of the American Institute of Indian Studies was examined in this section. The state wise decadal data (Edward, 1999) in terms of geographical area (thousand hectares) under different heads like net cultivable area, built up area, forest cover, intermittent wood cover, grass cover, and barren land were available. The statistical abstracts like mean and percentage change which took place by each head had been computed for all the states as well as all India from 1900 to 2013. These are presented in table 16.

Over India, area under net cultivation increased by 83.5 per cent during 2013 than 1900 and it was 44.56 per cent of total area in 1900. The built up area showed an increase by five times or more within the time period. This was mainly due to the urbanization and urban sprawling. Intermittent wood, grasslands, and barren land decreased by 90.3, 84.0, and 51.3 per cent respectively. During the same period, forest cover increased by 12.77 per cent. The recent change of land use and land cover from 2000 to 2013 is represented in table 17. Area under net cultivation and built up was found to increase by four per cent and 11 per cent during the period 2000 to 2013. Forest cover was found to increase by 3 per cent for the same period. Intermittent wood, grass land, and barren land declined by 8.35 per cent, 3.95 per cent, and 1.14 per cent respectively.

The area under net cultivation over Kerala state (1763.73 thousand hectares) in 1900 had increased to 2835.7 thousand hectares in 2013. In recent decades, area under net cultivation showed a decrease by 14.27 per cent from 2000 to 2013. The major change took place in the state of Kerala during this study period was in the area under built up. Due to the rapid increase in population in this coastal state as well as in industrialization, the area under the built up (45.24 thousand hectares) in 1900 had increased to 448.1 thousand hectares in 2013. Forest cover in Kerala was found to decrease by 27.34 per cent within the same period. Decreasing area of intermittent wood, grass land, and barren land (Desert) were 93.16 per cent, 99.69 per cent, and 48.94 per cent respectively. In recent years (2000-13), area under built up and forest cover was found to increase by 33.04 per cent and 15.18 per cent respectively from 2000 to 2013. Intermittent wood and barren land showed a decrease by 81.34 per cent and 43.6 per cent respectively over the same period.

It is clear that area under natural condition is decreasing mainly due to the human influence. Increase in human population as well as the rapid urbanization across the country do make excessive demands on natural resources as well as the proper management of the land use and land cover. However, the changes in the land use and land cover across the country differed from one place to another due to the physiographic, orographic and climatic conditions of the region. The land use and land cover change analysis in this study were restricted only to the administrative units (states or union territories).

Though very small in its geographical coverage, the maximum increase in area under net cultivation was noticed in Nagaland during the period 1900 to 2013. With continuous increase in the human population and its associated need of food security, the area under net cultivation across the country increased except in Odisha, Tamil Nadu, Bihar, and Delhi. In Odisha, 73.15 per cent of reduction in net cultivation observed during the period. Due to its small geographical area and rapid urbanization of being the capital of the country, Delhi recorded 43.21 per cent decrease in the net cultivable area while other two states Tamil Nadu and Bihar showed a slight decrease during the period. North Eastern states and Union territories recorded maximum increase in built up area. Highest loss in forest cover during the period is in Odisha (74.34 per cent) followed by Bihar (70.01 per cent), Haryana (67.70 per cent), Uttar Pradesh (47.03 per cent). Andaman and Nicobar Island recorded an increase of 8.12 per cent intermittent wood while Gujarat recorded a decrease of 99.75 per cent. The maximum loss of grass land was observed in West Bengal (99.75 per cent). A maximum increase of grass land was observed in Himachal Pradesh, which was two times or more than that of 1900. Most of the central Indian states and North

Eastern states showed an increasing tendency in barren land. The area under wet land including fresh water showed maximum decrease in Manipur (52.93 per cent) while an increase of 51.88 per cent was noticed over Himachal Pradesh during the study period.

In recent years (Table 17), the maximum increase in net cultivation observed in Manipur was 47.88 per cent from 2000 to 2013. All other northeastern states showed a rise in area under net cultivation. Odisha showed a maximum decline in net cultivation by 35.66 per cent over the period. Maximum increase in built up area was observed in Arunachal Pradesh, which was five times or more in 2013 than 2000. Maximum increase in forest cover observed in West Bengal (57.16 %) while maximum decrease observed in Bihar (27.47 %) followed by Punjab (27.14 %). Maximum increase in intermittent wood observed in Punjab by two times or more over the period from 2000 to 2013, followed by Rajasthan (66.12 %). Maximum decline in intermittent wood observed in Kerala (81.34 %) over the period. Maximum increase in grass land reported in Arunachal Pradesh by three times or more while maximum decline reported in Mizoram by 77.14 per cent. Maximum increase in barren land observed in Arunachal Pradesh (81.93 %) followed by Punjab (81.03 %). Maximum decrease in barren land was found in West Bengal (53.61 %).

Table 16. Changes in land use and land cover (LULC) pattern across India from 1900-2013

Year	Geographical area (thousand hectares)					
	Net Cultivation	Built up	Forest	Intermittent Wood	Grasses	Desert/ Barren
All India						
1900	103781	4029.76	62021.07	34486.97	65131.92	35508.91
2013	190435.3	25203.25	69940.68	3344.304	10423.42	17285.02
Change (%)	83.5	525.4	12.8	-90.3	-84.0	-51.3
Andaman and Nicobar Island						
1900	5.91	0.53	648.49	8.47	18.86	2.34
2013	20.74	12.0	717.06	9.16	5.06	2.16
Change (%)	250.95	2164.95	10.57	8.12	-73.16	-7.77
Andhra Pradesh						
1900	10063.66	284.27	4972.06	4144.56	6773.59	477.63
2013	13138.2	2736.0	6209.49	287.07	614.24	2060.33
Change (%)	30.55	862.46	24.88	-93.07	-90.93	331.36
Arunachal Pradesh						
1900	52.08	2.75	6072.03	592.36	112.88	1474.5
2013	266.57	22.87	5154	38.09	16.84	38.09
Change (%)	411.84	731.50	-15.11	-93.56	-85.08	-97.42
Assam						
1900	1078.38	53.06	3267.66	1155.54	1408.94	33.46
2013	4005.17	1137.96	1902.64	202.79	159.93	1430.51
Change (%)	271.41	2044.67	-41.77	-82.45	-88.65	4175.28
Bihar						
1900	8873.6	402.86	2072.07	1547.83	3351.65	319.85
2013	7661.02	1663.87	621.23	240.37	16.82	434.22
Change (%)	-13.67	313.01	-70.02	-84.47	-99.5	35.76
Delhi						
1900	95.09	8.13	1.9	12.06	18.56	9.81
2013	45.55	75.47	1.26	1.15	0.06	15.12
Change (%)	-52.1	828.25	-33.64	-90.48	-99.67	54.18
Gujarat						
1900	6476.7	245.93	1126.96	1529.88	4820.07	2714.53
2013	11589.02	1156.51	1820.82	3.78	851.04	2578.62
Change (%)	78.93	370.25	61.57	-99.75	-82.34	-5.01

Table 16 (Contd…)

Year	Geographical area (thousand hectares)					
	Net Cultivation	Built up	Forest	Intermittent Wood	Grasses	Desert/ Barren
Haryana						
1900	2524.32	101.04	146.46	494.71	834.97	280.05
2013	6372.17	456.01	47.3	9.1	26.93	101.24
Change (%)	152.43	351.31	-67.71	-98.16	-96.77	-63.85
Himachal Pradesh						
1900	563.23	25.52	1561.93	163.22	479.91	2712.21
2013	949.06	395.54	1103.4	64.89	1506.99	732.1
Change (%)	68.50	1449.92	-29.36	-60.28	214.01	-73.01
Jammu and Kashmir						
1900	510.27	31.79	2046.02	634.99	996.65	8752.81
2013	1123.7	290.85	2023	68.55	124.1	290.37
Change (%)	120.22	814.90	-1.13	-89.21	-87.55	-96.68
Karnataka						
1900	7137.56	375.8	3732.88	1204.16	5110.58	370.23
2013	12324.01	1368.17	3071.21	293.45	932.68	788.02
Change (%)	72.66	264.07	-17.73	-75.63	-81.75	112.85
Kerala						
1900	1763.73	45.24	1488.6	121.72	62.05	48.94
2013	2835.7	448.1	1081.59	8.32	0.19	24.99
Change (%)	60.78	890.48	-27.34	-93.16	-99.69	-48.94
Lakshadweep						
1900	1.0	0.04	0	1.81	0.2	0.1
2013	2.84	0.73	0	0.05	0.1	0.1
Change (%)	183.88	1730.23	0	-97.24	-50	0
Madhya Pradesh						
1900	11970.17	285.1	14893.44	8093.61	7438.9	277.16
2013	20375.36	1993.45	8688.34	20.61	1370.023	1385.25
Change (%)	70.22	599.21	-41.66	-99.75	-81.58	399.80
Maharashtra						
1900	15896.85	264.55	5042.96	2752.3	6428.42	180.07
2013	22252.68	1412.92	5203.35	261.25	1235.08	1695.78
Change (%)	39.98	434.09	3.18	-90.51	-80.79	841.73

Table 16 (Contd…)

Year	Geographical area (thousand hectares)					
	Net Cultivation	Built up	Forest	Intermittent Wood	Grasses	Desert/ Barren
Meghalaya						
1900	82.25	5.25	769.62	1152.04	195.79	13.49
2013	296.51	93.8	946.62	159.33	505.77	134.43
Change (%)	260.50	1686.6	23.0	-86.17	158.32	896.52
Manipur						
1900	84.62	5.54	536.6	1403.44	32.55	22.36
2013	251.59	25.97	1734.46	5.94	1.38	0.94
Change (%)	197.31	368.70	223.23	-99.58	-95.74	-95.79
Mizoram						
1900	32.4	1.24	830.45	1158.14	65.89	2.11
2013	99.72	112.85	1592.06	31.63	7.4	9.04
Change (%)	207.77	9000.81	91.71	-97.27	-88.77	328.36
Nagaland						
1900	51.2	2.93	674.18	542.04	336.32	15.74
2013	409.97	79.13	862.79	114.11	725.38	2.83
Change (%)	700.77	2600.74	27.98	-78.95	115.68	-82.00
Odisha						
1900	3410.97	134.71	5535.01	2188.76	3255.68	48.64
2013	915.99	568.70	1420.05	553.03	886.84	-3.12
Change (%)	-73.15	322.17	-74.34	-74.73	-72.76	-106.42
Punjab						
1900	2969.31	105.75	20.67	186.66	1402.92	231.1
2013	7887.35	454.4	291.62	4.90	4.13	30.04
Change (%)	165.63	329.69	1310.82	-97.37	-99.71	-87.0
Rajasthan						
1900	5294.31	201.8	482.8	1493.72	12538.26	13962.82
2013	21568.49	1836.99	2694.25	17.29	1701.60	2433.78
Change (%)	307.39	810.30	458.05	-98.84	-86.43	-82.57
Sikkim						
1900	20.38	0.77	240.87	53.52	137.74	246.8
2013	127.88	29.94	543.23	7.63	4	107
Change (%)	527.47	3788.27	125.53	-85.75	-97.1	-56.65

Table 16 (Contd…)

Year	Geographical area (thousand hectares)					
	Net Cultivation	Built up	Forest	Intermittent wood	Grasses	Desert/ Barren
Tamil Nadu						
1900	6017.03	529.44	1897.6	1406.91	1943.92	317.75
2013	5756.08	2122.42	2121.03	265.08	112.75	492.03
Change (%)	-4.34	300.88	11.77	-81.16	-94.2	54.85
Tripura						
1900	56.92	3.00	395.07	513.18	40.32	5.33
2013	299.88	136.60	618.65	19.57	2.62	7.33
Change (%)	426.84	4453.18	56.59	-96.19	-93.50	37.52
Uttar Pradesh						
1900	14497.35	646.37	3152.17	1631.08	5348.65	2798.83
2013	25344.04	2702.86	1669.66	356.89	66.18	523.78
Change (%)	74.82	318.16	-47.03	-78.12	-98.76	-81.29
West Bengal						
1900	4251.74	267.42	412.63	300.33	1977.7	190.26
2013	9515.71	1712.07	1177.27	56.32	4.89	22.20
Change (%)	123.81	540.22	185.31	-81.25	-99.75	-88.33

Table 17. Changes in land use and land cover (LULC) pattern across India from 2000-2013

Year	Geographical area (thousand hectares)					
	Net Cultivation	Built up	Forest	Intermittent Wood	Grasses	Desert/ Barren
All India						
2000	185340.38	23751.84	67553.80	3444.77	10661.60	17482.67
2013	194398.98	26453.97	69789.80	3157.24	10240.25	17283.63
Change (%)	4.89	11.38	3.31	-8.35	-3.95	-1.14
Andaman and Nicobar Island						
2000	44.00	1.00	693.00	2.00	6.00	3.00
2013	24.53	6.00	671.10	4.09	3.69	1.64
Change (%)	-44.25	500.00	-3.16	104.30	-38.55	-45.37
Andhra Pradesh						
2000	13545.00	2624.00	4463.70	269.00	675.00	2100.00
2013	13649.96	2873.29	4611.60	278.46	514.54	1959.44
Change (%)	0.77	9.50	3.31	3.52	-23.77	-6.69
Arunachal Pradesh						
2000	245.00	5.00	6804.50	46.00	4.00	21.00
2013	284.57	26.20	6732.10	36.14	18.32	38.21
Change (%)	16.15	423.94	-1.06	-21.43	357.93	81.93
Assam						
2000	4092.00	1079.00	2771.40	209.00	160.00	1453.00
2013	4197.04	1212.07	2767.10	195.84	159.67	1408.38
Change (%)	2.57	12.33	-0.16	-6.30	-0.21	-3.07
Bihar						
2000	7992.00	1638.00	572.00	231.00	18.00	437.00
2013	7777.52	1708.38	729.10	246.34	15.60	431.72
Change (%)	-2.68	4.30	27.47	6.64	-13.32	-1.21
Delhi						
2000	53.00	75.00	11.10	1.00	--	13.00
2013	48.75	76.22	1.48	1.17	0.06	16.48
Change (%)	-8.02	1.62	-86.69	17.00	--	26.78
Gujarat						
2000	10440.00	1129.00	1515.20	4.00	851.00	2600.00
2013	12599.72	1171.10	1465.30	3.60	851.40	2551.50
Change (%)	20.69	3.73	-3.29	-10.00	0.05	-1.87

Table 17 (Contd…)

Year	Geographical area (thousand hectares)					
	Net Cultivation	Built up	Forest	Intermittent Wood	Grasses	Desert/ Barren
Haryana						
2000	6115.00	368.00	175.40	7.00	34.00	102.00
2013	6375.54	541.75	158.60	4.15	24.97	101.44
Change (%)	4.26	47.21	-9.58	-40.74	-26.57	-0.55
Himachal Pradesh						
2000	948.00	314.00	1436.00	57.00	1529.00	807.00
2013	946.59	352.67	1468.30	64.91	1507.52	778.53
Change (%)	-0.15	12.31	2.25	13.87	-1.40	-3.53
Jammu and Kashmir						
2000	1115.00	291.00	2123.70	72.00	126.00	291.00
2013	1162.09	307.09	2253.80	65.48	114.24	306.38
Change (%)	4.22	5.53	6.13	-9.05	-9.33	5.28
Karnataka						
2000	12284.00	1312.00	3699.10	303.00	959.00	794.00
2013	11747.86	1435.60	3613.20	282.67	908.34	786.62
Change (%)	-4.36	9.42	-2.32	-6.71	-5.28	-0.93
Kerala						
2000	3022.00	382.00	1556.00	15.00	0.06	29.00
2013	2591.73	508.22	1792.20	2.80	0.12	16.35
Change (%)	-14.24	33.04	15.18	-81.34	96.67	-43.61
Lakshadweep						
2000	1.00	0.04	2.70	1.81	0.20	0.10
2013	2.84	0.73	2.70	0.05	0.10	0.10
Change (%)	183.88	1730.23	0.00	-97.24	-50.00	0.00
Madhya Pradesh						
2000	17870.00	1889.00	7726.50	20.00	1585.00	1349.00
2013	23129.79	2126.08	7752.20	19.96	1285.88	1387.16
Change (%)	29.43	12.55	0.33	-0.22	-18.87	2.83
Maharashtra						
2000	21619.00	1364.00	4748.20	328.00	1168.00	1544.00
2013	21873.61	1455.60	5063.20	250.90	1244.70	1721.70
Change (%)	1.18	6.72	6.63	-23.51	6.57	11.51

Table 17 (Contd…)

Year	Geographical area (thousand hectares)					
	Net Cultivation	Built up	Forest	Intermittent Wood	Grasses	Desert/ Barren
Meghalaya						
2000	277.00	87.00	1558.40	155.00	--	136.00
2013	339.73	107.51	1728.80	164.30	--	131.73
Change (%)	22.64	23.58	10.93	6.00	--	-3.14
Manipur						
2000	209.00	26.00	1692.60	5.94	1.47	0.95
2013	309.07	27.96	1699.20	5.95	1.37	0.94
Change (%)	47.88	7.53	0.39	0.12	-6.61	-1.16
Mizoram						
2000	82.00	122.00	1749.40	31.00	23.00	16.00
2013	115.98	137.00	1905.40	41.08	5.25	8.25
Change (%)	41.44	12.30	8.92	32.53	-77.17	-48.44
Nagaland						
2000	336.00	66.00	1334.50	125.00	--	--
2013	488.52	92.68	1304.40	93.72	--	2.50
Change (%)	45.39	40.43	-2.26	-25.02	--	--
Odisha						
2000	7878.00	999.00	4883.80	482.00	443.00	843.00
2013	5068.59	1305.00	5034.70	198.00	536.00	1104.00
Change (%)	-35.66	30.63	3.09	-58.92	20.99	30.96
Punjab						
2000	7941.00	409.00	243.20	3.00	4.00	28.00
2013	7870.14	429.43	177.20	8.94	4.95	50.69
Change (%)	-0.89	4.99	-27.14	197.87	23.68	81.03
Rajasthan						
2000	19230.00	1740.00	1636.70	14.00	1707.00	2566.00
2013	23953.60	1864.43	1608.60	23.26	1694.50	2410.74
Change (%)	24.56	7.15	-1.72	66.12	-0.73	-6.05
Sikkim						
2000	117.00	143.00	319.30	5.00	4.00	107.00
2013	143.72	150.00	335.80	7.77	--	--
Change (%)	22.84	4.90	5.17	55.32	--	--

Table 17 (Contd…)

Year	Geographical area (thousand hectares)					
	Net Cultivation	Built up	Forest	Intermittent wood	Grasses	Desert/ Barren
Tamil Nadu						
2000	6338.00	1986.00	2148.20	255.00	123.00	476.00
2013	5139.83	2183.90	2384.40	249.54	109.57	488.51
Change (%)	-18.90	9.96	11.00	-2.14	-10.92	2.63
Tripura						
2000	301.00	131.00	706.50	27.00	--	--
2013	368.29	140.69	786.60	13.86	2.15	7.33
Change (%)	22.35	7.40	11.34	-48.66	--	--
Uttar Pradesh						
2000	25304.00	2436.00	1374.60	340.00	70.00	617.00
2013	25820.71	2892.68	1434.90	349.87	65.61	478.73
Change (%)	2.04	18.75	4.39	2.90	-6.27	-22.41
West Bengal						
2000	9117.00	1567.00	1069.30	57.00	4.00	27.00
2013	9677.80	1821.80	1680.50	49.79	2.77	12.52
Change (%)	6.15	16.26	57.16	-12.65	-30.83	-53.61

In Andhra Pradesh area under net cultivation increased to 13138.2 thousand ha (30.5 per cent) in recent decade than 1900. Area under built up and barren land increased to 2736 thousand ha (eight times more) and 2060.33 thousand ha (three times more) respectively in the last decade, 2013. Forest cover was found to increase by 6209.5 thousand ha (24.8 per cent) over the period. Area under intermittent wood and grass land decreased to 287.07 thousand ha (93.07 per cent) and 614.22 thousand ha (90.9 per cent) respectively in the last decade. In recent period from 2000 to 2013 (Table 17), area under net cultivation showed a smaller increase by 0.77 per cent. The area under built up, forest, and intermittent wood increased by 9.5, 3.31, and 3.52 per cent respectively. Area under grass lands and barren land were declined by 23.77 per cent and 6.69 per cent respectively.

In Arunachal Pradesh, the area under net cultivation increased to 266.7 thousand ha (four times more) in 2013 than in 1900. Forest cover was found to decrease by 5154 thousand ha (15 per cent) in last decade. Increase in area under built up was tremendous. Area under built up increased to 22.87 thousand ha (seven times or more) in the last decade than 1900. The area under intermittent wood, grass lands and barren land showed a decrease to 38.09 thousand ha (93.57 per cent), 16.84 thousand ha (85.08 per cent), and 38.1 thousand ha (97.42 per cent) respectively in 2010 decade than 1900. In recent period from 2000 to 2013 (Table 17), area under net cultivation showed an increase by 16.15 per cent. The area under built up, grass lands, and barren land increased by four times or more, three times or more, and 81.93 per cent respectively. Area under forest cover and intermittent wood were declined by 1.06 per cent and 21.43 per cent respectively.

In Assam, the area under net cultivation increased to 4005.17 thousand ha in 2010 than 1078.38 thousand ha in 1900. It showed an increase of two times or more over the period. The area under built up and barren land showed a tremendous increase over the period. The area under built up and barren land increased to 1137.96 thousand ha and 1430.51 thousand ha respectively in 2010 than 53.06 thousand ha and 33.46 thousand ha respectively in 1900. The increase were 20 and 41 times or more respectively for built up and barren land over the period. In recent period from 2000 to 2013 (Table 17), area under net cultivation and forest cover increased by 2.57 per cent and 12.33 per cent respectively. Area under forest, intermittent wood, grass lands, and barren land were found to decline by 0.16, 6.3, 0.21, and 3.07 per cent respectively.

In Andaman and Nicobar islands, the area under net cultivation reduced to 20.74 thousand ha in 2013 than 5.91 thousand ha in 1900. The percentage change over the period was two times or more. The area under built up increased to 12 thousand ha in 2010 than 0.53 thousand ha in 1900. The percentage increase over the period was 21 times or more. The area under forest cover declined to 717.06 thousand ha in 2010 than 648.49 thousand ha in 1900. The percentage change over the period was 10.57 per cent. The area under intermittent wood was found to increase by 9.16 thousand ha in 2013 than 8.47 thousand ha in 1900. The percentage change over the period was 8.12 per cent. The area under grass land decreased to 5.06 thousand ha in 2013 than 18.86 thousand ha in 1900. The percentage change over the period was 73.16 per cent. The area under barren land decreased to 2.16 thousand ha in 2013 than 2.34 thousand ha in 1900. The percentage change over the period was 7.77 per cent. In recent period from 2000 to 2013 (Table 17), area under net cultivation, forest cover, grass lands, and barren land decreased by 44.25, 3.16, 38.55, and 45.37 per cent respectively. Area under built up increased by five times or more within the period.

In Bihar, the area under net cultivation decreased to 8873.6 thousand ha in 2013 than 7661.02 thousand ha in 1900. The percentage change over the period was 13.66 per cent. The area under built up increased to 1663.87 thousand ha in 2013 than 402.86 thousand ha in 1900. The change over the period was three times or more than the past. The area under forest cover decreased to 621.23 thousand ha in 2013 than 2072.07 thousand ha in 1900. The percentage change over the period was 70.02 per cent. The area under intermittent wood reduced to 240.37 thousand ha in 2013 than 1547.83 thousand ha in 1900. The percentage change over the period was 84.47 per cent. The area under grass land decreased to 16.82 thousand ha in 2013 than 3351.65 thousand ha in 1900. The percentage change over the period was 99.5 per cent. The area under barren land increased to 434.22 thousand ha in 2013 than 319.85 thousand ha in 1900. The percentage change over the period was 35.76 per cent. In recent period from 2000 to 2013 (Table 17), area under net cultivation, grass lands, and barren land declined by 2.68, 13.32, 1.21 per cent respectively. Area under built up, forest, and intermittent wood increased by 4.3, 27.47, and 6.64 per cent respectively.

In Delhi, the area under net cultivation decreased to 45.55 thousand ha in 2013 than 95.09 thousand ha in 1900. The percentage change over the period was 52.1 per cent. The area under built up increased to 75.46 thousand ha in 2013 than 8.13 thousand ha in 1900. The percentage increase over the period was eight times or more. The area under forest cover decreased to 1.26 thousand ha in 2013 than 1.9 thousand ha in 1900. The percentage change over the period was 33.64 per cent. The area under intermittent wood decreased to 1.15 thousand ha in 2013 than 12.06 thousand ha in 1900. The percentage change over the period was 90.48 per cent. The area under grass land decreased to 0.06 thousand ha in 2013 than 18.56 thousand ha in 1900. The percentage change over the period was 99.67 per cent. The area under barren land increased to 15.12 thousand ha in 2013 than 9.81 thousand ha in 1900. The percentage change over the period was 54.18 per cent. In recent period from 2000 to 2013 (Table 17), area under net cultivation and forest cover were found to decline by 8.02 and 86.69 per cent respectively. Area under built up, intermittent wood, and barren land increased by 1.62, 17.0, and 26.78 per cent respectively.

In Gujarat, the area under net cultivation increased to 11589.02 thousand ha in 2013 than 6476.7 thousand ha in 1900. The percentage change over the period was 78.93 per cent. The area under built up increased to 1156.51 thousand ha in 2013 than 245.93 thousand ha in 1900. The percentage increase over the period was three times or more. The area under forest cover increased to 1820.82 thousand ha in 2013 than 1126.96 thousand ha in 1900. The percentage change over the period was 61.57 per cent. The area under intermittent wood decreased to 3.78 thousand ha in 2013 than 1529.88 thousand ha in 1900. The percentage change over the period was 99.75 per cent. The area under grass land decreased to 851.04 thousand ha in 2013 than 4820.07 thousand ha in 1900. The percentage change over the period was 82.34 per cent. The area under barren land declined to 2578.62 thousand ha in 2013 than 2714.53 thousand ha in 1900. The percentage change over the period was 5.01 per cent. In recent period from 2000 to 2013 (Table 17), area under net cultivation, built up, and grass lands were found to increase by 20.69, 3.73, 0.05 per cent respectively. Area under forest cover, intermittent wood, and barren land reduced by 3.29, 10.0, and 1.87 per cent respectively.

In Haryana, the area under net cultivation increased to 6372.17 thousand ha in 2013 than 2524.32 thousand ha in 1900. The percentage increase was double over the period. The area under built up was found to increase to 456.01 thousand ha in 2013 than 101.04 thousand ha in 1900. The percentage change over the period was three times or more during the period (Table 17). The area under forest cover decreased to 47.3 thousand ha in 2013 than 146.46 thousand ha in 1900. The percentage change over the period was 67.71 per cent. The area under intermittent wood decreased to 9.1 thousand ha in 2013 than 494.71 thousand ha in 1900. The percentage change over the period was 98.16 per cent. The area under grass land decreased to 26.93 thousand ha in 2013 than 834.97 thousand ha in 1900. The percentage change over the period was 96.77 per cent. The area under barren land decreased to 101.24 thousand ha in 2013 than 280.05 thousand ha in 1900. The percentage change over the period was 63.85 per cent. The percentage change over the period was 5.01 per cent. In the recent period from 2000 to 2013 (Table 17), area under net cultivation and built up were found to increase by 4.26 per cent and 47.21 per cent respectively. Area under forest cover, intermittent wood, grass lands, and barren land decreased by 9.58, 40.74, 26.57, and 0.55 per cent respectively.

In Himachal Pradesh, the area under net cultivation increased to 949.06 thousand ha in 2013 than 563.23 thousand ha in 1900. The percentage change over the period was 68.50 per cent. The area under built up increased to 395.54 thousand ha in 2013 than 25.52 thousand ha in 1900. The percentage increase over the period was 14 times or more. The area under forest cover decreased to 1103.4 thousand ha in 2013 than 1561.93 thousand ha in 1900. The percentage change over the period was 29.36 per cent. The area under intermittent wood decreased to 64.83 thousand ha in 2013 than 163.22 thousand ha in 1900. The percentage change over the period was 60.28 per cent. The area under grass land increased to 1506.99 thousand ha in 2013 than 479.91 thousand ha in 1900. The percentage increase over the period was two times or more. The area under barren land decreased to 732.1 thousand ha in 2013 than 2717.21 thousand ha in 1900. The percentage change over the period was 73.01 per cent. In recent period from 2000 to 2013 (Table 17), area under net cultivation, grass lands, and barren land were found to decline by 0.15, 1.4, and 3.53 per cent respectively. Area under built up, forest cover, and intermittent wood showed an increase by 12.31, 2.25, and 13.87 per cent respectively.

In Jammu and Kashmir, the area under net cultivation increased to 1123.7 thousand ha in 2013 than 510.27 thousand ha in 1900. The percentage increase over the period was double. The area under built up increased to 290.85 thousand ha in 2013 than 31.79 thousand ha in 1900. The percentage increase over the period was eight times or more. The area under forest cover decreased to 2023 thousand ha in 2013 than 2046.02 thousand ha in 1900. The percentage change over the period was 1.13 per cent. The area under intermittent wood decreased to 68.55 thousand ha in 2013 than 634.99 thousand ha in 1900. The percentage change over the period was 89.21 per cent. The area under grass land decreased to 124.10 thousand ha in 2013 than 996.65 thousand ha in 1900. The percentage change over the period was 87.55 per cent. The area under barren land decreased to 290.37 thousand ha in 2013 than 8752.81 thousand ha in 1900. The percentage change over the period was 96.68 per cent. The percentage change over the period was 73.01 per cent. In the recent period from 2000 to 2013 (Table 17), area under net cultivation, built up, forest cover, and barren land were found to increase by 4.22, 5.53, 6.13, and 5.28 per cent respectively. Area under intermittent wood and grass lands were found to decline by 9.05 and 9.33 per cent respectively.

In Karnataka, the area under net cultivation increased to 12324.01 thousand ha in 2013 than 7137.56 thousand ha in 1900. The percentage change over the period was 72.66 per cent. The area under built up increased to 1368.17 thousand ha in 2013 than 375.8 thousand ha in 1900. The percentage increase over the period was eight times or more. The area under forest cover decreased to 3071.21 thousand ha in 2013 than 3732.88 thousand ha in 1900. The percentage change over the period was 17.73 per cent. The area under intermittent wood decreased to 293.45 thousand ha in 2013 than 1204.16 thousand ha in 1900. The percentage change over the period was 75.63 per cent. The area under grass land decreased to 932.68 thousand ha in 2013 than 5110.58 thousand ha in 1900. The percentage change over the period was 81.75 per cent. The area under barren land increased to 788.02 thousand ha in 2013 than 370.23 thousand ha in 1900. The percentage increase was double over the period. In recent period from 2000 to 2013 (Table 17), area under built up showed an increase by 9.42 per cent. Area under net cultivation, forest cover, intermittent wood, grass lands, and barren land were found to decline by 4.36, 2.32, 6.71, 5.28, and 0.93 per cent respectively.

In Lakshadweep islands, the area under net cultivation increased to 2.84 thousand ha in 2013 than 1.0 thousand ha in 1900. The percentage change over the period was double. The area under built up increased to 0.73 thousand ha in 2013 than 0.04 thousand ha in 1900. The percentage increase over the period was 17 times or more. No forest cover was recorded over the time period. The area under intermittent wood decreased to 0.05 thousand ha in 2013 than 1.81 thousand ha in 1900. The percentage change over the period was 97.24 per cent. The area under grass land decreased to 0.1 thousand ha in 2013 than 0.2 thousand ha in 1900. The percentage change over the period was 50 per cent. The area under barren land was same (0.1 thousand ha) for the time period. The percentage increase was double over the period. In recent period from 2000 to 2013 (Table 17), area under net cultivation increased by almost double. Area under built up increased by 18 times or more. Area under intermittent wood and grass land were also found to decline by 97.24 and 50 per cent respectively.

In Madhya Pradesh, the area under net cultivation increased to 20375.36 thousand ha in 2013 than 11970.17 thousand ha in 1900. The percentage change over the period was 70.22 per cent. The area under built up increased to 1993.45 thousand ha in 2013 than 285.1 thousand ha in 1900. The percentage increase over the period was five times more (1900-2013). The area under forest cover decreased to 8688.34 thousand ha in 2013 than 14893.44 thousand ha in 1900. The percentage change over the period was 41.66 per cent. The area under intermittent wood decreased to 20.61 thousand ha in 2013 than 8093.61 thousand ha in 1900. The percentage change over the period was 99.75 per cent. The area under grass land decreased to 1370.03 thousand ha in 2013 than 7438.9 thousand ha in 1900. The percentage change over the period was 81.58 per cent. The area under barren land increased to 1395.25 thousand ha in 2013 than 277.16 thousand ha in 1900. The percentage increase over the period was three times or more for the same. The percentage increase was double over the period. In recent period from 2000 to 2013 (Table 17), area under net cultivation, built up, forest cover, and barren land were found to increase by 29.43, 12.55, 0.33, and 2.83 per cent respectively. Area under intermittent wood and grass land were found to decrease by 0.22 and 18.87 per cent respectively.

In Maharashtra, the area under net cultivation increased to 22252.68 thousand ha in 2013 than 15896.85 thousand ha in 1900. The percentage change over the period was 39.98 per cent. The area under built up increased to 1412.92 thousand ha in 2013 than 264.55 thousand ha in 1900. The percentage change over the period was four times more. The area under forest cover decreased to 5203.35 thousand ha in 2013 than 5042.96 thousand ha in 1900. The percentage change over the period was 3.18 per cent. The area under intermittent wood decreased to 261.25 thousand ha in 2013 than 2752.3 thousand ha in 1900. The percentage change over the period was 90.51 per cent. The area under grass land declined to 1235.08 thousand ha in 2013 than 6428.42 thousand ha in 1900. The percentage change over the period was 80.78 per cent. The area under barren land increased to 1695.78 thousand ha in 2013 than 180.07 thousand ha in 1900. The percentage change over the period was 841.73 per cent. The percentage increase was double over the period. In recent period from 2000 to 2013 (Table 17), area under net cultivation, built up, forest cover, grass lands, and barren land were found to increase by 1.18, 6.72, 6.63, 6.57, and 11.51 per cent respectively.

In Meghalaya, the area under net cultivation increased to 296.51 thousand ha in 2013 than 82.25 thousand ha in 1900. The percentage increase was double over the period. The area under built up increased to 93.8 thousand ha in 2013 than 5.25 thousand ha in 1900. The percentage increase over the period (1900-2013) was 16 times or more. The area under forest cover increased to 946.62 thousand ha in 2013 than 769.62 thousand ha in 1900. The percentage change over the period was 23 per cent. The area under intermittent wood decreased to 159.33 thousand ha in 2013 than 1152.04 thousand ha in 1900. The percentage change over the period was 86.17 per cent. The area under grass land increased to 505.77 thousand ha in 2013 than 195.79 thousand ha in 1900. The percentage change over the period was 158.32 per cent. The area under barren land increased to 134.43 thousand ha in 2013 than 13.49 thousand ha in 1900. The percentage increase over the period was eight times or more. In recent period from 2000 to 2013 (Table 17), area under net cultivation, built up, forest cover, and grass lands were found to increase by 22.64, 23.58, 10.93, and 6.0 per cent respectively. Area under barren land was declined by 3.14 per cent over the period.

In Manipur, the area under net cultivation increased to 251.59 thousand ha in 2013 than 84.62 thousand ha in 1900. The percentage increase over the period was double. The area under built up increased to 25.97 thousand ha in 2013 than 5.54 thousand ha in 1900. The percentage increase over the period was three times or more. The area under forest cover increased to 1734.46 thousand ha in 2013 than 536.6 thousand ha in 1900. The percentage change over the period was double for the same. The area under intermittent wood decreased to 5.94 thousand ha in 2013 than 1403.44 thousand ha in 1900. The percentage change over the period was 99.58 per cent. The area under grass land decreased to 1.38 thousand ha in 2013 than 32.55 thousand ha in 1900. The percentage change over the period was 95.75 per cent. The area under barren land decreased to 0.94 thousand ha in 2013 than 22.36 thousand ha in 1900. The percentage change over the period was 95.79 per cent. The percentage increase over the period was eight times more. In recent period from 2000 to 2013 (Table 17), area under net cultivation, built up, forest cover, intermittent wood were found to increase by 47.88, 7.53, 0.39, 0.12 per cent respectively. Area under grass lands and barren land were declined by 6.61 and 1.16 per cent respectively over the period.

In Mizoram, the area under net cultivation increased to 99.72 thousand ha in 2013 than 32.4 thousand ha in 1900. The percentage increase was double over the period. The area under built up increased to 112.85 thousand ha in 2013 than 1.24 thousand ha in 1900. The area under forest cover increased to 1592.06 thousand ha in 2013 than 830.45 thousand ha in 1900. The percentage change over the period was 91.71 per cent. The area under intermittent wood decreased to 31.63 thousand ha in 2013 than 1158.14 thousand ha in 1900. The percentage change over the period was 97.27 per cent. The area under grass land decreased to 7.4 thousand ha in 2013 than 65.89 thousand ha in 1900. The percentage change over the period was 88.77 per cent. The area under barren land increased to 9.04 thousand ha in 2013 than 2.11 thousand ha in 1900. The percentage change over the period was three times or more. In recent period from 2000 to 2013 (Table 17), area under net cultivation, built up, forest cover, intermittent wood increased by 41.44, 12.30, 8.92, and 32.53 per cent respectively. Area under grass lands and barren land were found to decline by 77.17 and 48.44 per cent respectively over the period.

In Nagaland, the area under net cultivation increased to 409.97 thousand ha in 2013 than 51.2 thousand ha in 1900. The percentage increase over the period was seven times or more. The area under built up increased to 79.13 thousand ha in 2013 than 2.93 thousand ha in 1900. The percentage increase over the period was 26 times or more. The area under forest cover increased to 862.79 thousand ha in 2013 than 674.18 thousand ha in 1900. The percentage change over the period was 27.98 per cent. The area under intermittent wood decreased to 114.11 thousand ha in 2013 than 542.04 thousand ha in 1900. The percentage change over the period was 78.95 per cent. The area under grass land increased to 725.38 thousand ha in 2013 than 336.32 thousand ha in 1900. The percentage increase over the period was double. The area under barren land decreased to 2.83 thousand ha in 2013 than 15.74 thousand ha in 1900. The percentage change over the period was 82.0 per cent. In recent period from 2000 to 2013 (Table 17), area under net cultivation and built up were found to increase by 45.39 and 40.43 per cent respectively. Area under forest cover and intermittent wood were decreased by 2.26 and 25.02 per cent respectively.

In Odisha, the area under net cultivation decreased to 915.99 thousand ha in 2013 than 3410.97 thousand ha in 1900. The percentage change over the period was 73.15 per cent. The area under built up increased to 568.7 thousand ha in 2013 than 134.71 thousand ha in 1900. The percentage increase over the period was three times or more. The area under forest cover decreased to 1420.05 thousand ha in 2013 than 5535.01 thousand ha in 1900. The percentage change over the period was 74.34 per cent. The area under intermittent wood decreased to 553.03 thousand ha in 2013 than 2188.76 thousand ha in 1900. The percentage change over the period was 74.73 per cent. The area under grass land decreased to 886.84 thousand ha in 2013 than 3255.68 thousand ha in 1900. The percentage change over the period was 72.76 per cent. The area under barren land decreased to 3.12 thousand ha in 2013 than 48.64 thousand ha in 1900. The percentage change over the period was 106.42 per cent. In recent period from 2000 to 2013 (Table 17), area under net cultivation and intermittent wood were found to decrease by 35.66 and 58.92 per cent respectively. Area under built up, forest cover, grass lands, and barren land increased by 30.63, 3.09, 20.99, and 30.96 per cent respectively for the same period.

In Punjab, the area under net cultivation increased to 7887.35 thousand ha in 2013 than 2969.31 thousand ha in 1900. The percentage increase over the period was double. The area under built up increased to 454.39 thousand ha in 2013 than 105.75 thousand ha in 1900. The percentage increase over the period was three times or more. The area under forest cover increased to 291.62 thousand ha in 2013 than 20.67 thousand ha in 1900. The percentage increase over the period was 13 times or more. The area under intermittent wood decreased to 4.9 thousand ha in 2013 than 186.66 thousand ha in 1900. The percentage change over the period was 97.37 per cent. The area under grass land decreased to 4.13 thousand ha in 2013 than 1402.92 thousand ha in 1900. The percentage change over the period was 99.70 per cent. The area under barren land decreased to 30.04 thousand ha in 2013 than 231.1 thousand ha in 1900. The percentage change over the period was 87.0 per cent. In recent period from 2000 to 2013 (Table 17), area under net cultivation and forest cover decreased by 0.89 and 27.14 per cent respectively. Area under intermittent wood is increased nearly by two times or more over the period. Area under built up, grass lands, and barren land were found to increase by 4.99, 23.68, and 81.03 per cent respectively for the same period.

In Rajasthan, the area under net cultivation increased to 21568.49 thousand ha in 2013 than 5294.31 thousand ha in 1900. The percentage increase over the period was three times or more. The area under built up increased to 1836.99 thousand ha in 2013 than 201.8 thousand ha in 1900. The percentage increase over the period was eight times or more. The area under forest cover increased to 2694.25 thousand ha in 2013 than 482.8 thousand ha in 1900. The percentage increase over the period was four times or more. The area under intermittent wood decreased to 17.29 thousand ha in 2013 than 1493.72 thousand ha in 1900. The percentage change over the period was 98.84 per cent. The area under grass land decreased to 1701.6 thousand ha in 2013 than 12538.26

thousand ha in 1900. The percentage change over the period was 86.43 per cent. The area under barren land decreased to 2433.78 thousand ha in 2013 than 13962.82 thousand ha in 1900. The percentage change over the period was 82.57 per cent. In recent period from 2000 to 2013 (Table 17), area under net cultivation, built up and intermittent wood were found to increase by 24.56, 7.15 and 66.12 per cent respectively. Area under forest cover, grass lands, and barren land were declined by 1.72, 0.73, and 6.05 per cent respectively.

In Sikkim, the area under net cultivation increased to 127.88 thousand ha in 2013 than 20.38 thousand ha in 1900. The percentage increase over the period was five times or more. The area under built up increased to 29.94 thousand ha in 2013 than 0.77 thousand ha in 1900. The percentage increase over the period was 37 times or more. The area under forest cover increased to 543.23 thousand ha in 2013 than 240.87 thousand ha in 1900. The percentage increase over the period was nearly double. The area under intermittent wood decreased to 7.63 thousand ha in 2013 than 53.52 thousand ha in 1900. The percentage change over the period was 85.75 per cent. The area under grass land decreased to 4.0 thousand ha in 2013 than 137.74 thousand ha in 1900. The percentage change over the period was 97.1 per cent. The area under barren land decreased to 107 thousand ha in 2013 than 246.8 thousand ha in 1900. The percentage change over the period was 56.65 per cent. In recent period from 2000 to 2013 (Table 17), area under net cultivation, built up, forest cover, and intermittent wood was found to increase by 22.84, 4.90, 5.17 and 55.32 per cent respectively.

In Tamil Nadu, the area under net cultivation decreased to 5756.078 thousand ha in 2013 than 6017.03 thousand ha in 1900. The percentage change over the period was 4.34 per cent. The area under built up increased to 2122.22 thousand ha in 2013 than 529.44 thousand ha in 1900. The percentage increase over the period was three times or more. The area under forest cover increased to 2121.03 thousand ha in 2013 than 1897.6 thousand ha in 1900. The percentage change over the period was 11.77 per cent. The area under intermittent wood decreased to 265.08 thousand ha in 2013 than 1406.91 thousand ha in 1900. The percentage change over the period was 81.16 per cent. The area under grass land decreased to 112.75 thousand ha in 2013 than 1943.92 thousand ha in 1900. The percentage change over the period was 94.2 per cent. The area under barren land increased to 492.03 thousand ha in 2013 than 317.75 thousand ha in 1900. The percentage change over the period was 54.84 per cent. In recent period from 2000 to 2013 (Table 17), area under net cultivation, intermittent wood, and grass land were found to decrease by 18.90, 2.14, and 10.92 per cent respectively. Area under built up, forest cover, and barren land increased by 9.96, 11.0, and 2.63 per cent respectively.

In Tripura, the area under net cultivation increased to 299.88 thousand ha in 2013 than 56.92 thousand ha in 1900. The percentage increase over the period was four times or more. The area under built up increased to 136.6 thousand ha in 2013 than 3.0 thousand ha in 1900. The percentage increase over the period was 44 times or more. The area under forest cover increased to 618.65 thousand ha in 2013 than 395.07 thousand ha in 1900. The percentage change over the period was 56.59 per cent. The area under intermittent wood decreased to 19.57 thousand ha in 2013 than 513.18 thousand ha in 1900. The percentage change over the period was 96.18 per cent. The area under grass land decreased to 2.62 thousand ha in 2013 than 40.32 thousand ha in 1900. The percentage change over the period was 93.5 per cent. The area under barren land increased to 7.33 thousand ha in 2013 than 5.33 thousand ha in 1900. The percentage change over the period was 37.52 per cent. In recent period from 2000 to 2013 (Table 17), area under net cultivation, built up, and forest cover were found to increase by 22.35, 7.4, and 11.34 per cent respectively. Area under intermittent wood was decreased by 48.66 per cent.

In Uttar Pradesh, the area under net cultivation increased to 25344.04 thousand ha in 2013 than 14497.35 thousand ha in 1900. The percentage change over the period was 74.81 per cent. The area under built up increased to 2702.86 thousand ha in 2013 than 646.37 thousand ha in 1900. The percentage increase over the period was tree times or more. The area under forest cover decreased to

1669.66 thousand ha in 2013 than 3152.17 thousand ha in 1900. The percentage change over the period was 47.03 per cent. The area under intermittent wood decreased to 356.89 thousand ha in 2013 than 1631.08 thousand ha in 1900. The percentage change over the period was 78.12 per cent. The area under grass land decreased to 66.18 thousand ha in 2013 than 5348.65 thousand ha in 1900. The percentage change over the period was 98.76 per cent. The area under barren land decreased to 523.78 thousand ha in 2013 than 2798.83 thousand ha in 1900. The percentage change over the period was 81.29 per cent. In recent period from 2000 to 2013 (Table 17), area under net cultivation, built up, forest cover, and intermittent wood were found to increase by 2.04, 18.75, 4.39, and 2.9 per cent respectively. Area under grass lands and barren land were decreased by 6.27 and 22.41 per cent respectively.

In West Bengal, the area under net cultivation increased to 9515.709 thousand ha in 2013 than 4251.74 thousand ha in 1900. The percentage increase over the period was nearly double. The area under built up increased to 1712.07 thousand ha in 2013 than 267.42 thousand ha in 1900. The percentage increase over the period was five times or more. The area under forest cover increased to 1177.27 thousand ha in 2013 than 412.63 thousand ha in 1900. The percentage increase over the period was double. The area under intermittent wood decreased to 56.32 thousand ha in 2013 than 300.33 thousand ha in 1900. The percentage change over the period was 81.25 per cent. The area under grass land decreased to 4.89 thousand ha in 2013 than 1977.7 thousand ha in 1900. The percentage change over the period was 99.75 per cent. The area under barren land decreased to 22.2 thousand ha in 2013 than 190.26 thousand ha in 1900. The percentage change over the period was 88.33 per cent. In recent period from 2000 to 2013 (Table 17), area under net cultivation, built up, and forest cover were found to increase by 6.15, 16.26, and 57.16 per cent respectively. Area under intermittent wood, grass lands, and barren land were decreased by 12.65, 30.83, and 53.61 per cent respectively.

Major parts of the country experienced a decline in rainfall trend. This was found to be inconsistent with the shrinking tendency in deserts of the whole

India based on land use and cover (LULC) data. It was observed that states like Andhra Pradesh, Karnataka, Tamil Nadu, Madhya Pradesh, and Maharashtra experienced increase in barren land. This was consistent with the decreasing rainfall trend over central peninsular India, south peninsular India, west coast, and west coast south. The built up area across the country showed a tremendous increasing trend due to the rapid increase in human population and urbanization. The area under forest cover across the country showed a small increasing (12 per cent) tendency. This may be due to lot of afforestation activities followed by government or non-governmental organizations during 1980 onwards. An increase in population makes excessive demands on natural resources, and increases the demand on agriculture and livestock. The increasing trend observed in the area under net cultivable land of the country seems to be one of the initial steps taken by the humans in their limited capacities to meet the food security of the rising population. Thus the changes in land use and land cover seemed to be mostly human driven during the recent decades rather than climate change.

The major LULC changes included the loss of forests, expansion of cropland, and urbanization which occurred during 1900–2013. However, deforestation decreased after the 1980s due to formulation of government policies to protect forests. Cropland expansion rate was greater primarily due to expansion of irrigation facilities, farm mechanization, electrification, and use of high yielding crop varieties that resulted from Government policies of achieving self-sufficiency in food production. Our results had shown that urbanization which was negligible during earlier period became one of the most important land conversions in the recent decades due to population and economic growth in India. This is in agreement with the reports of Tian *et al*., 2014.

From the study it was found that area under barren land or desert is decreasing. This is in agreement with the studies of Singh *et al.* (1992). According to the study, decreasing tendency in the arid area of the country was reported (Singh *et al*., 1992). Earlier, some studies showed that the Indian desert was spreading (Winstanley, 1973).

4.3 Climate change and environmental processes

Changes in the natural cycle of the environment due to man-made interventions in the process of development may lead to global warming and climate change and vice-versa, having benevolent and malevolent effects in the society linked sectors viz., water, agriculture, health, forestry, biodiversity, industry and sea level.The environment processes include the changes in the atmosphere, lithosphere, cryosphere, hydrosphere and biosphere. Since, all the above are interlinked with each other, the natural environment as a whole is under threat due to human interventions. Therefore, changes in atmospheric processes in terms of global tropospheric, surface air temperature and the zonal rainfall versus land use pattern such as barren land, desertification, urbanization and wetlands over the country are presented and discussed hereunder:

4.3.1 Global tropospheric temperature

The global tropospheric temperature indicated that there was an increase of 0.59^{o}C after climate shift, commencing from 1979 to 2014 (Table 18). It was more over the southern hemisphere (0.87 ^{o}C) than over the northern hemisphere (0.32 ^{o}C). The difference in the tropospheric temperature between both the hemispheres was 0.55 ^{o}C. Higher tropospheric temperature over the Southern hemisphere was due to the heat capacity of oceans. The heat capacity over the water is much higher when compared to land regions. Regions of high temperatures lead to low atmospheric pressure. Both the temperature and pressure gradient between the two hemispheres are the key driving forces for movement of air masses, leading to changes in wind pattern and atmospheric circulation. It may be one of the causal factors for monsoon aberrations over India.

The results are in agreement with the findings of Sooraj *et al*. (2014). As per the assessments from the CMIP5 models, the warming scenario of the globe and the weakening of the Asian summer monsoon circulation had also been reported (Sooraj *et al*., 2014).

Table 18. Change in tropospheric temperature after climate shift (1978)

Regions	Change in tropospheric temperature after climate shift
Globe	0.59^{o}C
Southern hemisphere (SH)	0.87^{o}C
Northern hemisphere (NH)	0.32^{o}C
Difference between NH and SH	0.55

Table 29. Change in surface air temperature over the globe after climate shift (1978)

Regions	Mean from 1949-2014 (^{o}C)	Mean from 1949-1978 (^{o}C)	Mean from 1978-2014 (^{o}C)	Change (^{o}C)
Globe	14.67	14.51	14.81	0.30
Northern hemisphere	15.31	15.15	15.45	0.30
Southern hemisphere	14.03	13.87	14.17	0.29
Equator	26.71	26.51	26.87	0.36

Table 20. Change in surface air temperature over different climatic zones

Climatic zone	Mean from 1949-2014 (^oC)	Mean from 1949-1978 (^oC)	Mean from 1979-2014 (^oC)	Change (^oC)
Tropics (NH)	25.90	25.76	26.01	0.24
Tropics (SH)	24.75	24.58	24.88	0.30
Temperate (NH)	8.62	8.53	8.70	0.18
Temperate (SH)	9.98	9.94	10.01	0.07
Extra tropics (NH)	4.73	4.54	4.89	0.35
Extra tropics (SH)	3.32	3.16	3.45	0.29

(NH: Northern hemisphere, SH: Southern hemisphere)

Table 21. Change in all India mean temperatures

Seasons	Mean (1949-2007) (^oC)	Mean (1949-1978) (^oC)	Mean (1979-2007) (^oC)	Change (^oC)
Annual	24.4	24.3	24.5	0.22
Summer	27.1	27.1	27.1	0.03
Monsoon	27.6	27.5	27.7	0.21
Post-monsoon	23.1	22.9	23.3	0.41
Winter	18.2	18.1	18.4	0.31

4.3.2 Global surface air temperature

The mean surface air temperature over the globe was 14.67 ^{o}C over the period from 1949 to 2014. It was increased by 0.3 ^{o}C during post climate shift period (1979 to 2014). The mean surface air temperature over the northern hemisphere was 15.31 ^{o}C and the rise was 0.30 ^{o}C while the southern hemisphere recorded was 14.03 ^{o}C with an increase of 0.29 ^{o}C. The mean surface air temperature over the equator (5^{o}S–5^{o}N) was 26.71 ^{o}C with an increase of 0.36 ^{o}C (Table 19). The mean surface air temperature of the northern hemispheric tropics was 25.9 ^{o}C with an increase of 0.24 ^{o}C during post climate shift period while the southern hemispheric tropics recorded as 24.75 ^{o}C with a rise of 0.30 ^{o}C. The mean surface air temperature of the northern hemispheric temperate region was 8.62 ^{o}C with a rise of 0.18 ^{o}C during post climate shift period while the southern hemispheric temperate region recorded as 9.98 ^{o}C with a rise of 0.07 ^{o}C. The mean surface air temperature of the northern hemispheric extra tropics region was 4.73 ^{o}C with a rise of 0.35 ^{o}C during post climate shift period while the Southern hemispheric extra tropics region showed a temperature of 3.32 ^{o}C with a rise of 0.29 ^{o}C (Table 20). The study revealed that all the regions across the globe showed rise in surface air temperature during the period of post climate shift. It is obvious that warming is more over the tropics and the extra tropics when compared to that of the temperate belts in both the hemispheres due to the shape of the earth and its inclination towards the sun, resulting in more heat energy over the tropics. This is in agreement with the reports of IPCC, 2007 and IPCC 2013.

4.3.3 Temperature over India

Analysis of all India annual mean temperature showed an increase of 0.22 ^{o}C, with a mean of 24.4 ^{o}C over the period from 1949-2007. All seasons exhibited an increase of temperature (Table 21). The mean seasonal temperature for different seasons namely summer, Monsoon, post-monsoon, and winter were 27.1 ^{o}C, 27.6 ^{o}C, 23.1 ^{o}C, and 18.2 ^{o}C respectively. Among these maximum rise was observed during post-monsoon season (0.41 ^{o}C) followed by winter season (0.31 ^{o}C), monsoon (0.21 ^{o}C), and summer season (0.03 ^{o}C).

The results are in agreement with the reports of Rao *et al*. (2005); Jain and Kumar, (2012); and Paul *et al*. (2014).

With the global climate model projections of probable increase of global mean temperature between 1.4 and 5.8 °C by 2100 (IPCC, 2007), it is expected to have severe impacts on the global hydrological system, eco-systems, sea level, crop production and related produces. The latest report from the United Nation's Intergovernmental Panel on Climate Change (IPCC, 2013) stresses the risks of global warming. This is in agreement with the present study. This report predicts a rise in global temperatures of between 0.3 and 4.8 °C and a rise of up to 82 cm in sea levels by the late 21st century due to melting ice and expansion of water as it warms, threatening coastal cities around the globe. The likelihood, magnitude and timing are observed to be increasing and accelerating. Many projected consequences of global warming once thought controversial, are now being observed. Climate change has had an effect on the monsoons too. India is heavily dependent on the monsoon to meet its agricultural and water needs, and also for protecting and propagating its rich biodiversity. Eco-systems will be particularly vulnerable to climate change, with a study estimating that between 15 and 40 percent of species will face extinction with 2 °C of warming. Due to the fastened rate of warming, glaciers over the globe are expected to retreat.

In the wake of global climate change scenario, attempts have been made in recent decades world-wide to understand the various problems on regional and local scales. With this utmost need to understand the possible causes, the various meteorological parameters have been analysed at different isobaric levels in this study. The uneven thermal changes occurring at different levels as well as the different climatic zones over the globe had been found in this study which partly addresses the reason why it is happening in the wake of global warming.

Table 22. Number of lakes exceeding one square kilometre

Year	No. of lakes exceeding more than one square kilometre
1970	1081
2010	1236
New lakes expanded over the period	155

Table 23. Change in forest cover and stock of forest over Tibetan plateau

Year	Area under forest (Million ha)	Stock of forest (Bcm)
1997	7.29	2.09
2013	14.72	2.26
Percentage change	101.9	8.1

4.3.4 Climate change and glacier melting

Due to the glacier melting over the Tibetan plateau, the number and area of lakes on the plateau increased notably. The number of lakes exceeding one square kilometre climbed from 1081 in the 1970s to 1236 in 2010. Hence, 155 lakes in the region were expanding at a faster rate during the period (Table 22).

The area under forest and stock of forest on the plateau increased significantly since 1998, from 7.29 million hectares in 1997 to 14.72 million hectares in 2013. The stock of forest was increased from 2.09 billion cubic meters in 1997 to 2.26 billion cubic meters (8.1 %) in 2013 (Table 23).

The results are in agreement with the reports of Singh and Kumar, 1997; IPCC, 2007; Kang *et al*., 2010; IPCC, 2013; Nie *et al*., 2013; and Zhiguo, 2014.

4.3.5 Climate change and barren land

In the present study, the decreasing tendency of the all India summer monsoon rainfall was observed. It was observed that the weakening of the rainfall activities were due to the changing global climatic scenario over different climatic zones and at different isobaric levels. The paradoxical situation of the Asian summer monsoon is the weakening performance of summer monsoon rainfall though the surface air temperature of the northern hemisphere is rising. Summer monsoon rainfall is contributing more than 70 per cent of the annual rainfall. Over India, the Central Peninsular India (Fig. 33), South Peninsular India (Fig. 34), and West Coast (Fig. 35) experienced decline in annual rainfall because in those zones monsoon rainfall also showed a decreasing trend. The Indian states spread over these zones, viz. Madhya Pradesh, Maharashtra, Karnataka, Andhra Pradesh, and Tamil Nadu showed an increase in area under barren land.

The changes in barren land over selected states were represented in table 24. The area under barren land over Andhra Pradesh was increased to 2060323ha in 2010 than 477630ha in 1900. The percentage change over the period was 331.36 per cent. The area under barren land over Karnataka increased to

Table 34. Changes in barren land over selected states

Year	Geographical area (ha) under barren land				
	Andhra Pradesh	Karnataka	Tamil Nadu	Maharashtra	Madhya Pradesh
1900	477630	370230	317750	180070	277160
2013	2060327	788020	492030	1695780	1385250
Change (%)	331.36	112.85	54.85	841.73	399.80

Table 25. Land use and land cover changes over Rajasthan

Year	Geographical area (ha)		
	Desert	Forest	Wetland (1900-2011)
1900	13962820	482800	250200
2013	2433780	2694250	782314
Percentage change	-82.57	458.05	212.67

788020 ha in 2010 than 370230 ha in 1900. The percentage change over the period was 112.85 per cent. The area under barren land over Tamil Nadu was increased to 492030 ha in 2010 than 317750 ha in 1900. The percentage change over the period was 54.85 per cent. The area under barren land over Maharashtra increased to 1695780 ha in 2010 than 180070 ha in 1900. The percentage change over the period was eight times more than that of 1900. The area under barren land over Madhya Pradesh increased to 1385250 ha in 2013 than 277160 ha in 1900. The percentage change over the period was 399.80 per cent.

4.3.6 Climate change and desertification

From the decadal analysis of land use and land cover data, it was observed that area under desert declined from 13962820 ha in 1900 to 2433780 ha in 2010 (Table 25). It was observed that area under forest cover increased from 482800 ha in 1900 to 2694250 ha in 2010. The wetland was increased from 250200 ha in 1900 to 782314 ha in 2011.

Even though rainfall over North West India was declining the area under desert also showed a declining trend (Fig. 36). This may be due to the afforestation program and Indira Gandhi Canal for irrigation project over the state. So, the process of desertification might be arrested due to this. According to the studies undertaken by Space Application Centre, about 25 per cent of the country’s geographical area was affected by desertification. Desertification results in decline in water table and availability of water; reduced agricultural productivity; and loss of bio-diversity in the affected regions. Desertification is caused by a number of factors including climatic variations and human activities. Some of the human activities that can cause desertification are expansion of agriculture- over cultivation of soils, or exposure to erosion by wind or water; reduction in the fallow period of soil, and lack of organic or mineral fertilizers; overgrazing – often selectively – of shrubs, herbs and grasses; overexploitation of forest resources; deforestation; uncontrolled use of fire for regenerating pasture, for hunting, agricultural clearing, or for settling; and poor irrigation practices like

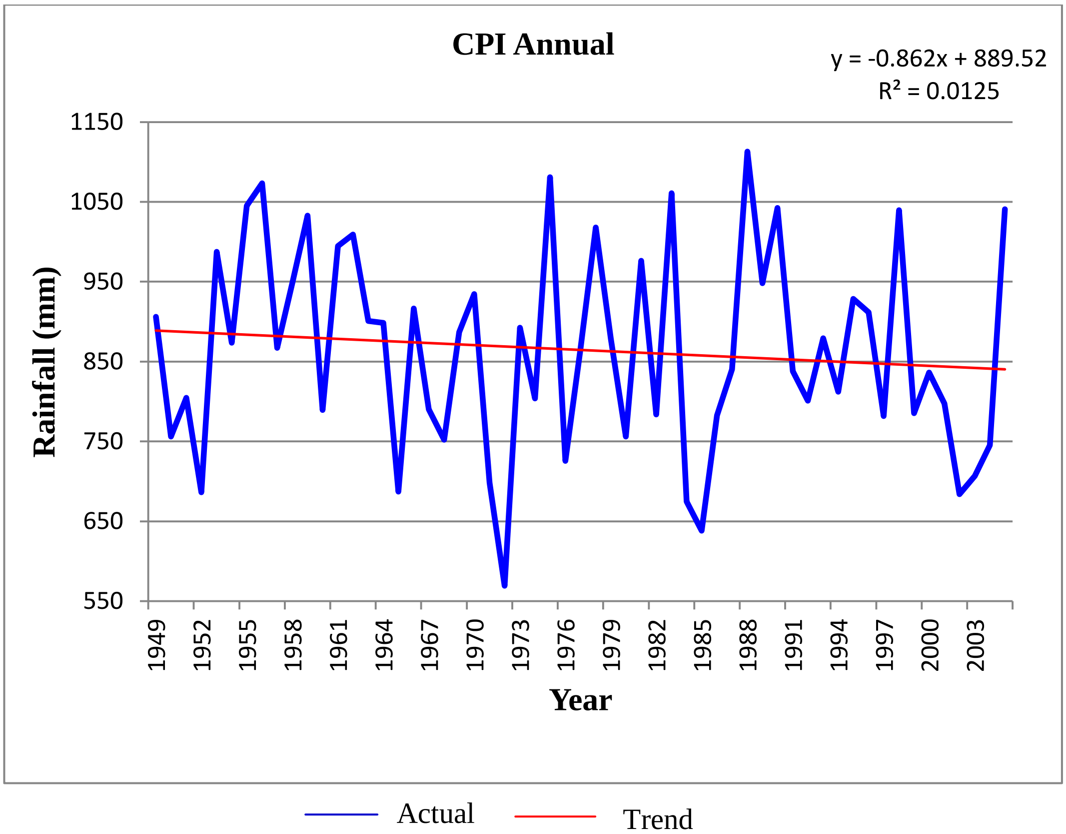


Fig. 33. Annual rainfall over Central Peninsular India from 1949 to 2005

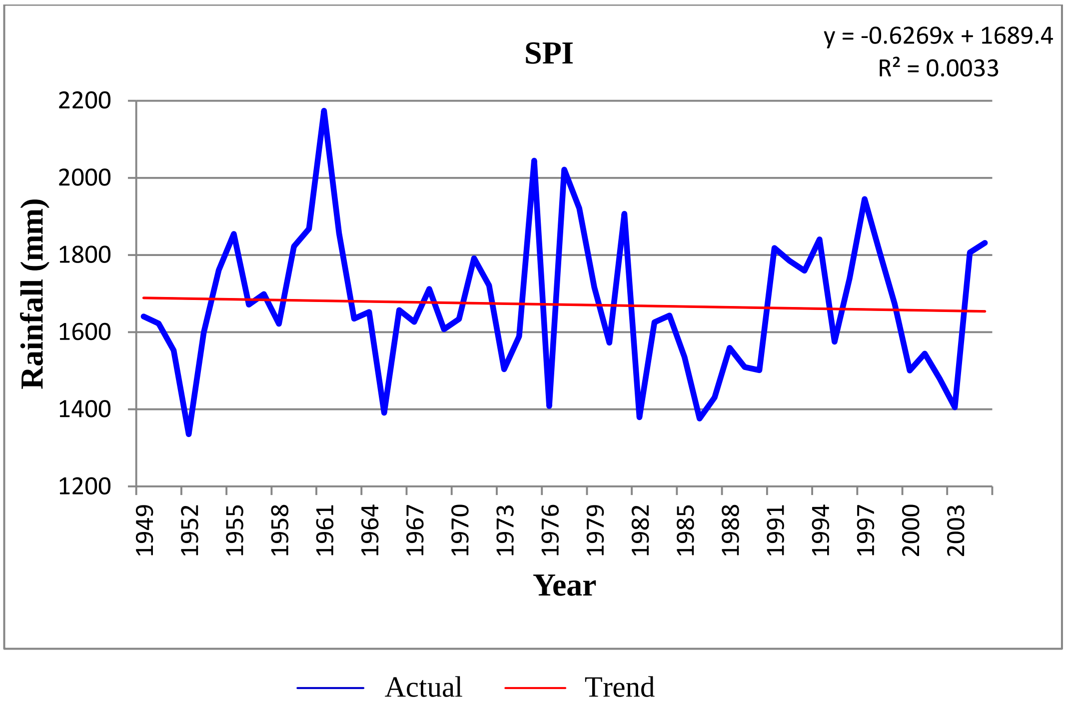


Fig. 34. Annual rainfall over South Peninsular India from 1949 to 2005

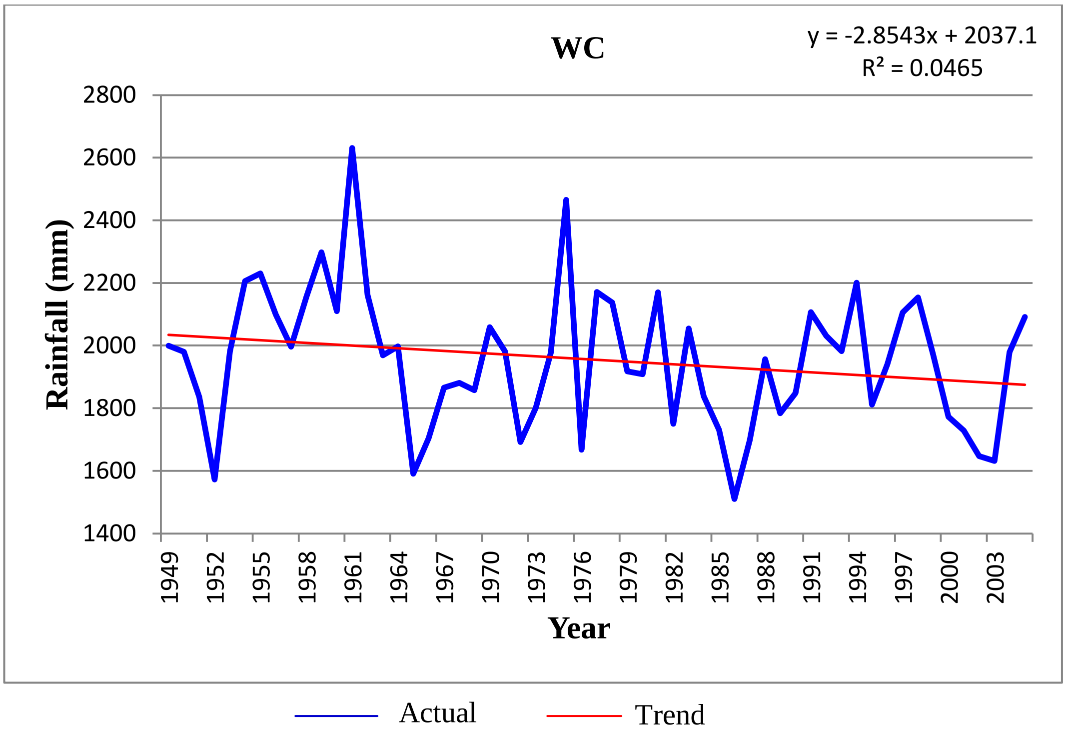


Fig. 35. Annual rainfall over West Coast from 1949 to 2005

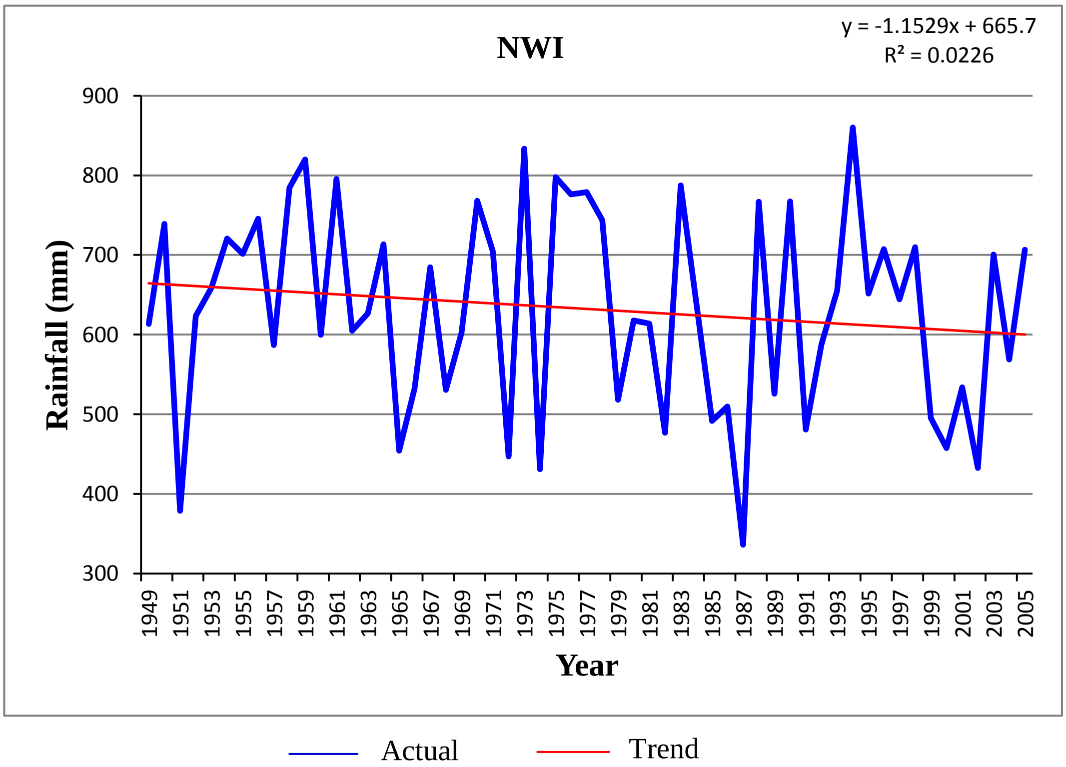


Fig. 36. Annual rainfall over North West India from 1949 to 2005

irrigation of soils prone to salinisation, alkalinisation or even water logging. In addition, living forests have multiple interactions with the climate system, far beyond their carbon content. The Space Application Centre in 2007 brought out the Desertification and Land Degradation Atlas which shows 81.45 million hectare land in the country has turned into arid, semi-arid or dry sub humid region. Kharol *et al*. (2013) have attributed recent land use or land cover changes (an increase in crop-land and vegetated areas of ~57 per cent in the eastern Rajasthan and ~68 per cent in the western Rajasthan) in the Rajasthan state due to the Indira Gandhi Canal (IGC). This is in agreement with the study.

The spatio-temporal rainfall variability led to the changes in the spatial coverage of the wetland and wasteland of the country. Rainfall variability has also large impact on land formation, biodiversity, desertification, food security etc.

4.3.8 Climate change and urbanization

Based on the analysis of area under built up (1900-2013), it was observed that area under built up increased from 4029760 ha in 1900 than 25203250 ha in 2013. Our results had shown that urbanization which was negligible during earlier period became one of the most important land conversions in the recent decades due to population and economic growth in India. This is in agreement with the reports of Tian *et al*. (2014).

The unconventional urban development and planning will lead to the increasing vulnerability of flood and extreme heat events. Cities are warmer than the surrounding countryside because the greater extent of paved areas in cities which affects exchange of water and energy between the land and the atmosphere. The impact was larger because of the unconventional land use practices like construction of roads and buildings over the river banks, land filling and deforestation. Multi-day cloud burst over the region resulted in the devastating floods and landslide.

Climate change is now considered one of the most serious threats to human development, as it has an adverse impact on natural resources, economic activities, food security, human health and physical infrastructure. It is one of the most important global environmental challenges. It involves complex interactions and changing likelihoods of diverse impacts. In recent decades, changes in climate have caused impacts on natural and human systems on the globe. That threat is greater in communities and areas where people's lives and livelihoods are more highly dependent on the use of natural resources. In these areas it is therefore very important to adapt to climate change in order to protect rural livelihoods and encourage sustainable development. Addressing the impact of climate change requires a good scientific understanding as well as coordinated action at national and global level.

Table 26. Changes in area under built up over India

Year	Geographical area (thousand hectares) under built up
1900	4029.76
2013	25203.25
Change (%)	525.42

SUMMARY AND CONCLUSIONS

CHAPTER 5
SUMMARY

The summary of results emerged out of this study are highlighted hereunder:

The mean all India annual rainfall during 1949-2014 was 1167.5 mm with the standard deviation of 106.8 mm. There was a decline (32.7 mm) in all India annual rainfall from pre- climate shift period (1949-78) to post-climate shift period (1949-2014) when the year 1978 was considered as the climate shift year. Decline in annual rainfall was mainly due to the decreasing tendency observed in the monsoon season (June to September) as it contributes 75.2 per cent of all India rainfall. In contrast, the seasonal rainfall during winter, summer and post-monsoon was showing an increasing trend. Interestingly, the monthly rainfall during June was increasing while decreasing trend in July, August and September with in the monsoon season.

The zonal trends in all India rainfall indicated that the three zones viz., the East Coast (N), the East Coast (S) and the North East India showed increase in rainfall. In contrast, rainfall decline was noticed in all other zones across the country viz., Central Peninsular India, Ganga Plains, North Central India, North Mountainous India, North West India, South Peninsular India, West Coast (S), and West Coast.

The area under very dry zone is decreasing from June to September since the country as a whole receives a good amount of monsoon rainfall and the active monsoon for the country commences by July only. Majority of the geographical area of the Country were under dry and very dry zone during all other seasons except during the summer monsoon season.

The global tropospheric temperature increased by 0.59 °C during the post climate shift period (1979 onwards) while it was 0.87 °C over the Southern hemisphere and 0.32 °C over the Northern hemisphere. Though the tropospheric temperature was increasing all over the globe, the rate of increase was high over the southern hemisphere, particularly over the temperate zone. The thermal contrast between the continental Asian region and the southern hemisphere temperate zone modulates the weaker Asia-Indian monsoon circulation and thus leading to declining trend in rainfall over India.

The mean sea level pressure (MSLP) during summer monsoon season increased by 1 to 7 hPa over the continental Asia (northern parts of India, Tibetan plateau, China, Mangolia) while the decrease in MSLP over the southern temperate regions was 1 to 3 hPa and it was intermediary (4-7 hPa) over the south polar region. Increase in the MSLP over continental Asia largely modulates the weakening of the convective activities over the region and in turn the declining summer monsoon rainfall trend observed during the last few decades. The post climatic shift global MSLP field was similar to that of the pattern exhibited during the bad monsoon year composite anomaly spatial plot. The troposphere shrunk by 60 m over continental Asia and inflated by 90 m over oceanic south temperate region after the climate shift (1979 onwards).

The sea surface temperature (SST) decreased by 0.2 to 0.6 °C over northern north pacific and increased by 0.2 to 0.8 °C over eastern south pacific (west of South America) during the summer monsoon season. The spatial plot of the SST composite anomaly for good monsoon years was almost similar to La Nina condition. Weak monsoon years showed the spatial pattern similar to that of El-Nino condition, indicating that El-Nino play a role directly or indirectly in rainfall variability over India but needs a proper investigation since always it is not related.

The total air column summer monsoon season precipitable water over and across India declined except over the north east India. These were clearly seen in the 9-point Gaussian low pass filtered values. Though showing the sharp and significant decreasing trend in the total air column summer monsoon season precipitable water, the cumulative effect observed through the 31-yr Cramer's $t_k$test statistic is not significant due to the large scale inter-annual variability. Due to warmer atmosphere, the precipitable water (PW) declined by 0.05 kg m^{-2} from 24kg m^{-2} to 23.95kg m^{-2}during the recent 30 years over India on annual scale but showed slight increasing during summer monsoon season. Though the total cloud cover over India showed a long term decreasing tendency, different zones show different nature of neither increasing nor decreasing tendencies except the highly significant (1% level of probability) trend found in the North East India.

In contrast to the earlier notion of having continuous expanding of the desert area, the desert or barren land areas showed randomly fluctuating characteristics of expansion or contraction but overall it showed a slight decreasing over the period of 1900-2013. Over India, area under net cultivation is increased by 83.5 per cent during 2010 than 1900 and it is 44.56 per cent of total area in 1900. The built up area increased by five times within the time period. Intermitted wood, grasslands, and barren land were decreased by 90.3 per cent, 84.0 per cent, and 51.3 per cent respectively. Changes in land use and land cover were mainly due to urbanization. It is clear that area under natural condition decreased mainly due to the human influence. Land used for arable cultivation as well as the built-up increased due the increase in the population on both the Kerala and the whole country.

In recent period, the maximum increase in net cultivation observed in Manipur by 47.88 per cent from 2000 to 2013. All other northeastern states showed a rise in area under net cultivation. Odisha showed a maximum decline in net cultivation by 35.66 per cent over the period. Maximum increase in built up area observed in Arunachal Pradesh, which is five times or more in 2013 than 2000. Maximum increase in forest cover observed in West Bengal (57.16 %) while maximum decrease found in Bihar (27.47 %) followed by Punjab (27.14 %). Maximum increase in intermittent wood observed in Punjab by two times or more over the period from 2000 to 2013, followed by Rajasthan (66.12 %). Maximum decline in intermittent wood is found in Kerala (81.34 %) over the period. Maximum increase in grass land was observed in Arunachal Pradesh by three times or more while maximum decline observed in Mizoram by 77.14 per cent. Maximum increase in barren land found in Arunachal Pradesh (81.93 %)

followed by Punjab (81.03 %). Maximum decrease in barren land observed in West Bengal (53.61 %).

Changes in the natural cycle of the environment due to man-made interventions in the process of development may lead to global warming and climate change and vice-versa. The mean surface air temperature over the globe was 14.67 ^{o}C over the period from 1949 to 2014. It was increased by 0.3 ^{o}C during post climate shift period (1979 to 2014). Analysis of all India annual mean temperature showed an increase of 0.22 ^{o}C, with a mean of 24.4 ^{o}C over the period from 1949-2007. Due to the glacier melting over the Tibetan plateau, the number and area of lakes on the plateau increased notably. The number of lakes exceeding one square kilometre climbed from 1081 in the 1970s to 1236 in 2010, and 80 per cent of lakes in the region was expanding at a faster rate. Over India, the Central Peninsular India, South Peninsular India, West Coast (S), and West Coast were experienced decline in annual rainfall because in those zones monsoon rainfall also showed a decreasing trend. The Indian states spread over these zones, viz. Madhya Pradesh, Maharashtra, Karnataka, Andhra Pradesh, and Tamil Nadu showed an increase in area under barren land. From the decadal analysis of land use and land cover data, it was observed that area under desert declined from 13962.82 thousand hectares in 1900 to 2433.78 thousand hectares in 2013. This may be due to the afforestation program and Indira Gandhi Canal for irrigation project over Rajasthan. So, the process of desertification might be arrested due to this. The area under built up (1900-2013), it was observed that area under built up was increased from 4029.76 thousand ha in 1900 than 25203.25 thousand ha in 2010.

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CHANGING GLOBAL CLIMATIC SCENARIO ON ENVIRONMENTAL PROCESSES ACROSS INDIA: ITS POSSIBLE CAUSES AND IMPACTS

By

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ABSTRACT OF THE THESIS

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ABSTRACT

Global warming is real. Polar ice is melting. Sea level is rising. One-third of plant and animal species is likely to be extinct in the decades to come. Rise in atmospheric temperature and sea surface temperature is likely to influence the atmospheric and environmental processes. Keeping this in view, present study was aimed with the objectives viz., to examine the rainfall variability across the country and its possible causes; to access the land use and land cover change of different parts of the country; to address the impacts of changing climatic scenario to the environmental processes. Rainfall data, atmospheric variables over land and ocean, land use and land cover data were collected from the India Meteorological Department and Indian Institute of Tropical Meteorology. The NCEP/NCAR reanalysis data were also used. The study was conducted in IITM using the available resources like GIS. Rainfall and meteorological parameters were analyzed during pre-climate and post-climate shift.

The mean all India annual rainfall showed a decline (32.7 mm) from pre-climate shift period (1949-78) to post-climate shift period (1979-2014) when the year 1978 was considered as the climate shift year. A significant decline in monsoon rainfall led to the decline in annual rainfall since 75.2 per cent of it is contributed during the monsoon season. Most of the geographical area of the country was under dry and very dry zone during all the three seasons except monsoon season. The zonal trends in all India rainfall indicated that the three zones viz., the East Coast (N), the East Coast (S) and the North East India (NEI) showed increase in rainfall while rainfall decline was noticed in all other zones across the country viz., Central Peninsular India, Ganga Plains, North Central India, North Mountainous India, North West India, South Peninsular India, West Coast (S), and West Coast. Decline in rainfall over India could be explained as due to changes that took place in land, ocean, and atmosphere continuum such as the tropospheric and surface temperatures, mean sea level pressure, sea surface temperature, geopotential height, precipitable water, and cloud amount.

Weakening of the summer monsoon rainfall is the result of variability in different meteorological parameters.

In recent years, the maximum increase in net cultivated area was observed in the state of Manipur by 47.88 per cent from 2000 to 2013. All other northeastern states showed a rise in area under net cultivation. Odisha showed a maximum decline in net cultivation by 35.66 per cent over the period. Maximum increase in built up area was observed in Arunachal Pradesh, which is five times or more in 2013 than 2000. Maximum increase in forest cover observed in West Bengal (57.16 %) while maximum decrease observed in Bihar (27.47 %) followed by Punjab (27.14 %). Maximum increase in intermittent wood was observed in Punjab by two times or more over the period from 2000 to 2013, followed by Rajasthan (66.12 %). Maximum decline in intermittent wood observed in Kerala (81.34 %) over the period. Maximum increase in grass land reported in Arunachal Pradesh by three times or more while maximum decline reported in Mizoram by 77.14 per cent. Maximum increase in barren land observed in Arunachal Pradesh (81.93 %) followed by Punjab (81.03 %). Maximum decrease in barren land was observed in West Bengal (53.61 %).

The mean surface air temperature over the globe was 14.67 ^{o}C over the period from 1949 to 2014. It was increased by 0.3 ^{o}C during post climate shift period (1979 to 2014). Analysis of all India annual mean temperature showed an increase of 0.22 ^{o}C, with a mean of 24.4 ^{o}C over the period from 1949-2007. Over India, the Central Peninsular India, South Peninsular India, West Coast (S), and West Coast were experienced decline in annual rainfall because in those zones monsoon rainfall also showed a decreasing trend. The Indian states spread over these zones, viz. Madhya Pradesh, Maharashtra, Karnataka, Andhra Pradesh, and Tamil Nadu showed an increase in area under barren land. The same process did not match with the arrest in desertification over Rajasthan. It could be explained due to large scale afforestation that took place in Rajasthan in addition to irrigation facilities provided through the prestigious Indira Gandhi Canal project.

Global warming and climate change are now considered one of the most serious threats to the society linked sectors as it had an adverse impact on natural resources and vice versa. In these sectors it is therefore very important to adapt to climate change for sustainable development. Addressing the impact of climate change requires a good scientific understanding as well as coordinated action at national, regional, and global level.